FORM PTO-1390 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	50212-362
	U.S. APPLIC. NO. (if known, see 37 CFR 1.5) **10/088300**

INTERNATIONAL APPLICATION NO. PCT/JP00/06442	INTERNATIONAL FILING DATE September 20, 2000	PRIORITY DATE CLAIMED September 20, 1999

TITLE OF INVENTION

METHOD OF MANUFACTURING OPTICAL LOSS FILTER, AND OPTICAL LOSS FILTER

APPLICANTS FOR DO/EO/US

Michiko TAKUSHIMA, Masakazu SHIGEHARA

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).

4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
    a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
    b. ☒ has been transmitted by the International Bureau.
    c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)

6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
    a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
    b. ☐ have been transmitted by the International Bureau.
    c. ☐ have not been made; however, the time limit for making such amendment has NOT expired.
    d. ☐ have not been made and will not be made.

8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.

14. ☐ A substitute specification.

15. ☐ A change of power of attorney and/or address letter.

16. ☒ Other items or information.
    - International Search Report prepared by the Japanese Patent Office
    - Front Page of the Published International Application
    - Form PCT/IB/304, 308

20277

PATENT TRADEMARK OFFICE

U.S. APPLIC. NO. (if known, see 37 CFR 1.50)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/088300	PCT/JP00/06442	50212-362

	CALCULATIONS	PTO USE ONLY

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):
Search Report has been prepared by the EPO or JPO $890.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) $710.00
No international preliminary examination fee paid to USPTO (37 CFR 1.482)
but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $740.00

Neither international preliminary examination fee (37 CFR 1.482) nor
international search fee (37 CFR 1.445(a)(2)) paid to USPTO $1,040.00

International preliminary examination fee paid to USPTO (37 CFR 1.482)
and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00

ENTER APPROPRIATE BASIC FEE AMOUNT =	$890.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

Claims	Number Filed	Number Extra	Rate		
Total Claims	3 -20 =	0	x $18.00	$0.00	
Independent Claims	16 -3 =	0	x $84.00	$0.00	
Multiple dependent claim(s) (if applicable)			+ $280.00	$0.00	
			TOTAL OF ABOVE CALCULATIONS =	$0.00	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				$0.00	
			SUBTOTAL =	$1020.00	
Processing fee of $130.00 for furnishing the English translation later than the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ 0.00	
			TOTAL NATIONAL FEE =	$1020.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$ 0.00	
			TOTAL FEES ENCLOSED =	$1020.00	
				Amount to be: refunded	$
				charged	$1020.00

a. ☐ A check in the amount of $ _____ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 500417 in the amount of $ 1020.00 to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 500417. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:	
	SIGNATURE Arthur J. Steiner
McDERMOTT, WILL & EMERY	NAME
600 13th Street, N.W.	26,106
Washington, DC 20005-3096	REGISTRATION NUMBER
(202) 756-8000	March 18, 2002
Facsimile (202) 756-8087	DATE

BASED ON FORM PTO-1390 (Rev. 5-93)

Docket No.: 50212-362   <u>PATENT</u>

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of   :
                                              :
Michiko TAKUSHIMA, et al.   :
                                              :
Serial No.:   :   Group Art Unit:
                                              :
Filed: March 18, 2002   :   Examiner:
                                              :
For: METHOD OF MANUFACTURING OPTICAL LOSS FILTER, AND OPTICAL LOSS
        FILTER

<u>PRELIMINARY AMENDMENT</u>

Commissioner for Patents
Washington, DC 20231

Sir:

Prior to examination of the above-referenced application, please amend the application as

follows:

IN THE SPECIFICATION:

Please amend page 14, line 3 to 5, as follows:

Fig. 4 is a graph showing the transmission characteristic of the optical loss filter shown in

Fig. 3A and Fig. 3B.

Please amend page 21, line 12, as follows:

In the long-period gratings LPG-a and LPG-c of this optical loss filter 200, the orders of

the cladding modes which can couple with the propagation mode in the core in the wavelength

band shown in Fig. 4 are different (the nth and mth orders). Under this condition, an nth cladding

mode $B_c{}''(L_c)$ occurs in the first-stage long-period grating LPG-c (the complex amplitude of the core mode with initial value $A_c(0)$ is $A_c(L_c)$), but almost no coupling of this cladding mode occurs in the second-stage grating LPG-a, and so there is no effect on the characteristics of LPG-a. Hence the initial value of the core mode for the second-stage grating LPG-a can be set to $A_c(L_c)$, and the initial value of the mth cladding mode $B_a{}''$ can be set equal to zero. Hence the complex amplitude finally obtained for the core mode, and the complex amplitude for the mth cladding mode, are equal in the case in which the second-stage long-period grating LPG-a exists independently (see Fig. 3B).

Please amend page 33, line 4, as follows:

In the optical loss filter shown in Fig. 8C, a long-period grating LPG-d_3 with a grating length Ld3 of 20 mm and refractive index fluctuation period Λ_{d3} of 347 μm, and a long-period grating LPG-e_3 with a grating length Le3 of 7 mm and refractive index fluctuation period Λ_{e3} of 351 μm, are provided in the axial direction of the optical fiber 10, separated by an interval 20 of 5 mm. This interval portion 20 is irradiated with ultraviolet light to provide a phase-shifting member. The refractive index fluctuation widths of the long-period gratings LPG-d_3 and LPG-e_3 are different.

IN THE CLAIMS:

Please replace claims 1-16 with claims 1-19, a clean copy of which is attached hereto.

REMARKS

The above-referenced application is amended to change the specification and claims. Attached hereto is a marked up version of the changes made to the specification and a clean copy of the claims as amended. Entry of this Preliminary Amendment is respectfully requested.

Respectfully submitted,

MCDERMOTT, WILL & EMERY

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Date: March 18, 2002

MARKED-UP VERSION OF THE SPECIFICATION

IN THE SPECIFICATION:

Page 14, line 3 to 5, has been amended as follows:

Fig. 4 is a graph showing the transmission characteristic of the optical loss filter shown in Fig. 3A and Fig. 3B.

Please amend page 21, line 12, as follows:

In the long-period gratings LPG-a and LPG-c of this optical loss filter 200, the orders of the cladding modes which can couple with the propagation mode in the core in the wavelength band shown in Fig. 4 are different (the nth and mth orders). Under this condition, an nth cladding mode $B_c^n(L_c)$ occurs in the first-stage long-period grating LPG-c (the complex amplitude of the core mode with initial value $A_c(0)$ is $A_c(L_c)$), but almost no coupling of this cladding mode occurs in the second-stage grating LPG-a, and so there is no effect on the characteristics of LPG-a. Hence the initial value of the core mode for the second-stage grating LPG-a can be set to $A_c(L_c)$, and the initial value of the mth cladding mode B_a^m can be set equal to zero. Hence the complex amplitude finally obtained for the core mode, and the complex amplitude for the mth cladding mode, are equal in the case in which the second-stage long-period grating LPG-a exists independently (see Fig. 3B).

Please amend page 33, line 4, as follows:

In the optical loss filter shown in Fig. 8C, a long-period grating LPG-d_3 with a grating length Ld3 of 20 mm and refractive index fluctuation period Λ_{d3} of 347 μm, and a long-period grating LPG-e_3 with a grating length Le3 of 7 mm and refractive index fluctuation period Λ_{e3} of 351 μm, are provided in the axial direction of the optical fiber 10, separated by an interval 20 of

5 mm. This interval portion 20 is irradiated with ultraviolet light to provide a phase-shifting member. The refractive index fluctuation widths of the long-period gratings LPG-d_3 and LPG-e_3 are different.

(Preliminary Amendment)

CLAIMS

1. A method of manufacturing an optical loss filter in an optical waveguide having a core with a prescribed refractive index, comprising:

5   a first process in which first and second long-period gratings are formed in the axial direction of the core having the photosensitivity of said optical waveguide, providing a prescribed interval therebetween; and,

10   a second process in which the core between said first long-period grating and said second long-period grating is irradiated with ultraviolet light.

2. A method of manufacturing an optical loss filter according to Claim 1, further comprising a third

15 process in which, prior to said first and second processes, or after both said processes, one or more third long-period gratings are formed.

3. A method of manufacturing an optical loss filter according to Claim 1, wherein, in said second

20 process, light in a prescribed usage wavelength band is input from one end of said optical waveguide, while light emitted from the other end of the optical waveguide is received, and the transmission characteristic of the optical loss filter obtained

25 based on the received light is monitored while performing irradiation with ultraviolet light.

(Preliminary Amendment)

4.   An optical loss filter manufactured by a method of manufacturing an optical loss filter according to Claim 1.

5.   A method of manufacturing an optical loss filter in an optical waveguide having a core with a prescribed refractive index, comprising:

a first process in which a first long-period grating, with constant refractive index fluctuation width and refractive index fluctuation period, is formed in the axial direction of the core having the photosensitivity of said optical waveguide; and,

a second process in which a prescribed region within a section in the axial direction of the core in which said first long-period grating is formed, excluding both ends of the section, is irradiated with ultraviolet light.

6.   A method of manufacturing an optical loss filter according to Claim 5, further comprising a third process in which, prior to said first and second processes, or after both said processes, one or more second long-period gratings are formed.

7.   A method of manufacturing an optical loss filter according to Claim 5, wherein, in said second process, light in a prescribed usage wavelength band is input from one end of said optical waveguide, while light emitted from the other end of the optical

waveguide is received, and the transmission
characteristic of the optical loss filter obtained
based on the received light is monitored while
performing irradiation with ultraviolet light.

5   8.   An optical loss filter manufactured by a
method of manufacturing an optical loss filter
according to Claim 5.

          9.   An optical loss filter, formed in an optical
waveguide having a core with a prescribed refractive
10   index, and used within a prescribed usage wavelength
band, comprising:

          a first long-period grating, provided in said
core, the refractive index fluctuation width of which
is a first fluctuation width, the refractive index
15   fluctuation period of which is a first period, and
having a first wavelength at which the maximum value of
attenuation due to coupling of the core mode with a
cladding mode is obtained;

          a second long-period grating, provided in said
20   core at a prescribed distance from said first long-
period grating, the refractive index fluctuation width
of which is a second fluctuation width, the refractive
index fluctuation period of which is a second period,
and having a second wavelength at which the maximum
25   value of attenuation due to coupling of the core mode
with a cladding mode is obtained; and,

a phase-shifting member, formed by irradiating the core between said first and second long-period gratings with ultraviolet light after formation of the first and second long-period gratings, and which causes a change

5   in the amount of phase rotation of the core mode.

10.   The optical loss filter according to Claim 9, having the relation

$$0 < \Delta N \le \lambda/\Delta L$$

where λ is an arbitrary wavelength within said

10   prescribed usage wavelength band, ΔL is the length of the optical waveguide in which said phase-shifting member is formed, and ΔN is the amount of change before and after the change in the refractive index of the core of said optical waveguide.

15   11.   The optical loss filter according to Claim 9, wherein said first period and said second period, and said first fluctuation width and said second fluctuation width, are respectively equal.

12.   The optical loss filter according to Claim 9,

20   wherein said first period and said second period are equal, and said first fluctuation width and said second fluctuation width are different.

13.   The optical loss filter according to Claim 9, wherein said first fluctuation width and said second

25   fluctuation width are equal, and said first period and said second period are different.

(Preliminary Amendment)

14. The optical loss filter according to Claim 9, wherein said first period and said second period, and said first fluctuation width and said second fluctuation width, are respectively different.

5
15. The optical loss filter according to Claim 9, wherein, within said prescribed usage wavelength band, the order of said core mode and the coupled cladding mode coincide in each of said first and second long-period gratings.

10
16. The optical loss filter according to Claim 9, wherein one or more third long-period gratings are further provided in said optical waveguide, and the refractive index fluctuation width of the third long-period grating differs from the refractive index

15
fluctuation width of said first and second long-period gratings.

17. The optical loss filter according to Claim 16, wherein, in said third long-period grating, the order of said cladding mode coupling with said core

20
mode within said prescribed usage wavelength band differs from that of the cladding mode coupling with the core mode in said first and second long-period gratings.

18. The optical loss filter according to Claim 9,

25
wherein one or more third long-period gratings are further provided in said optical waveguide, and the

(Preliminary Amendment)

refractive index fluctuation period of the third long-period grating differs from the refractive index fluctuation period of said first and second long-period gratings.

5   19.   The optical loss filter according to Claim 18, wherein, in said third long-period grating, the order of said cladding mode coupling with said core mode within said prescribed usage wavelength band differs from that of the cladding mode coupling with 10   the core mode in said first and second long-period gratings.

DESCRIPTION

METHOD OF MANUFACTURING OPTICAL LOSS FILTER, AND

OPTICAL LOSS FILTER

TECHNICAL FIELD

This invention relates to a method of

manufacturing an optical loss filter, which is an

optical component applicable to optical communications

and other fields, comprising a long-period fiber

grating to reduce the wavelength dependence of the gain

of rare earth-doped fiber amplifiers in particular, and

an optical loss filter manufactured by this method.

BACKGROUND ART

A representative optical fiber communication

system comprises an optical transmitter including a

light source, an optical fiber line, one end of which

is connected to this optical transmitter, and an

optical receiver, which is connected to the other end

of this optical fiber line. An optical amplifier, which

amplifies the optical signals in a prescribed

wavelength range, is installed in the optical fiber

line. In such an optical fiber communication system,

often WDM signals in the 1.5 μm band are used, and as

the optical amplifier, a fiber amplifier doped with

erbium (Er) or some other rare earth element is used.

This erbium-doped fiber amplifier (EDFA) forms an

inverted population of electron states with the EDFA by

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means of pumping light at a prescribed wavelength;
induced emission is caused by the injection of light in
the 1.5 μm band into the inverted population region,
resulting in amplification of the incident light.

In such an optical fiber communication system, the
amplified spontaneous emission (ASE) generated through
the interaction within the EDFA of the pumping light
power and Er ions becomes a noise component. This ASE
causes a decline in gain and an increase in the noise
figure, and because the ASE has a power distribution
with a peak at 1.53 μm, if optical amplification is
repeated by a plurality of EDFAs, scattering occurs in
the gain of optical signals with different wavelength
components, under the influence of the ASE power
distribution (a wavelength dependence occurs in the
amplification gain of the optical amplifier).
Consequently, in WDM (wavelength division multiplexing)
systems in which a plurality of optical signals with
different wavelengths are transmitted, different gains
occur for each channel (for each optical signal), and
so there is the problem that bit error rates are higher
for a number of channels as a result.In order to
resolve these problems, an optical loss filter
comprising a wavelength-selective, non-reflective long-
period grating was developed as a gain equalizer for
EDFA or the like.

This long-period grating has a periodic structure with periodically differing refractive indices, formed within the core along the axis of an optical waveguide, and is a grating which induces coupling between the

5   core mode and cladding mode propagating along the optical waveguide. The period of this grating is set such that the optical path length difference between the core mode and cladding mode within one period is equal to a prescribed wavelength, so that there is

10   strong power conversion from the core mode to a cladding mode. As a result, the long-period grating acts to radiate the core mode, and the core mode intensity is attenuated over a narrow band centered on a prescribed wavelength (the loss wavelength).

15   The central wavelength of the wavelength spectrum of light coupled from the core to the cladding by the long-period grating, that is, the loss wavelength, is determined by the following equation.

$$\beta_{core}^{(lm)} - \beta_{cladding}^{(n)} = 2\pi \ / \ \Lambda \qquad\qquad (1)$$

20   Here l, m are core mode orders (for the fundamental mode LP01, l=0, m=1), $\beta_{core}^{(lm)}$ is the core mode propagation constant specified by (lm), $\beta_{cladding}^{(n)}$ is the propagation constant of the nth cladding mode, and Λ is the period of the long-period grating.

25   The propagation constants β_{core}, $\beta_{cladding}$ are wavelength-dependent parameters; from the above

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equation (1), it is seen that by adjusting the period
Λ when forming the long-period grating, the loss
wavelength of the long-period grating can be
controlled. In addition, β_{core} depends on the effective
refractive index of the core, and $\beta_{cladding}$ depends on
the effective refractive index of the cladding, so that
when the grating period is held constant, the loss
wavelength of the long-period grating depends mainly on
the difference in the effective refractive index of the
core and cladding in the portion in which the long-
period grating is formed. The effective refractive
index of the core where the grating is formed can be
regarded as based on the average value of a modulated
refractive index; the difference in effective
refractive index of core and cladding in the grating
formation portion depends on the difference between the
average value of the refractive index of core and the
average value of the refractive index of cladding. The
amplitude of core refractive index fluctuation changes
according to the amount of irradiation of ultraviolet
rays during grating formation, and the core refractive
index changes accordingly; hence by adjusting the
amount of ultraviolet ray irradiation when forming the
long-period grating, the effective refractive index
difference between core and cladding can be adjusted,
and the loss wavelength of the long-period grating can

be controlled.

Normally, EDFA of 1.55 μm band has a sharp gain peak near 1530 nm and two broad peaks between 1540 and 1560, as shown in Fig. 20. Consequently as one method of configuring a gain equalizer having a long-period grating with a transmission characteristic like that shown in Fig. 21, a so-called phase-shifting long-period grating (reference 1: Electron. Lett., Vol. 34, No. 11, p. 1132, 1998; reference 2: IEICE Tech. Rep., OPE98-111, p. 13, 1998), which brings the transmission characteristics closer to the EDFA loss profile by changing the phase difference between the core and cladding modes between two gratings, may be used.

DISCLOSURE OF THE INVENTION

As a result of studies of the above-described conventional technology, the inventors discovered the following problem. In the preceding technology described in Reference 1, although gain flattening is achieved over the broad range of a wavelength band of 30 nm, the gain deviation is a large 2 dB, and characteristics could not be called adequate. On the other hand, in the preceding technology described in Reference 2, gain flattening is achieved, with a gain deviation of 0.2 dB; but because gain peaks near 1530 nm are outside the used band, the band is narrow at 24 nm. Also, when the preceding technology described in

Reference 2 is used as a method of manufacturing such a phase-shifting long-period grating, a condensing lens and stage are employed to make the refractive index fluctuation one period at a time, using a method of

5   shifting the amount of movement of the stage midway; this method requires highly precise stage control, and it is difficult to easily and precisely obtain the desired transmission characteristics.

Hence an object of this invention is to provide a

10   method of manufacturing an optical loss filter by means of which prescribed transmission characteristics can be obtained easily and with good precision, and which can be manufactured in compact form, as well as an optical loss filter manufactured by this method.

15   A method of manufacturing an optical loss filter of this invention is a method of manufacturing an optical loss filter in an optical waveguide having a core with a prescribed refractive index, and comprises a first process in which first and second long-period

20   gratings are formed, with a prescribed interval provided between, in the axial direction of a core having the photosensitivity of the optical waveguide, and a second process in which the core between the first long-period grating and second long-period

25   grating is irradiated with ultraviolet light.

In this method of manufacturing an optical loss

filter, by forming the first and second long-period
gratings in the first process, an initial transmission
characteristic is obtained through the combination of
the first and second long-period gratings. And by
5   irradiating the core with ultraviolet light in the
second process, this initial transmission
characteristic is modified. Because the amount of
irradiation of the core with ultraviolet light can be
changed continuously, by adjusting the irradiation
10   amount, the desired transmission characteristic can be
obtained easily and with good precision. Also, the
number of long-period gratings formed can be reduced,
so that manufacturing in compact form is possible.

In a method of manufacturing an optical loss
15   filter of this invention, prior to the first process
and the second process, or after both these processes,
a third process, in which one or more third long-period
gratings are formed, can also be comprised. By this
means, further diversification of the transmission
20   characteristic of the optical loss filter can be
achieved.

A method of manufacturing an optical loss filter
of this invention is a method of manufacturing an
optical loss filter in an optical waveguide having a
25   core with a prescribed refractive index, comprising a
first process, in which a first long-period grating,

with constant refractive index fluctuation width and refractive index fluctuation period, is formed in the axial direction of a core having the photosensitivity of an optical waveguide, and a second process, in which a prescribed region within a section in the axial direction of the core in which the first long-period grating is formed, excluding both ends of the section, is irradiated with ultraviolet light.

In this method of manufacturing an optical loss filter, by forming a first long-period grating in the first process, an initial transmission characteristic is obtained. And, by irradiating the core with ultraviolet light in the second process, this initial transmission characteristic is modified. Because the amount of irradiation of the core with ultraviolet light can be changed continuously, by adjusting the irradiation amount, the desired transmission characteristic can be obtained easily and with good precision. Also, the number of long-period gratings formed can be reduced, so that manufacturing in compact form is possible.

In a method of manufacturing an optical loss filter of this invention, prior to the first process and the above second process, or after both these processes, a third process, in which one or more second long-period gratings are formed, can also be comprised.

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By this means, further diversification of the transmission characteristic of the optical loss filter can be achieved.

In a method of manufacturing an optical loss filter of this invention, it is preferable that in a second process, light in a prescribed usage wavelength band is input from one end of the optical waveguide, while light emitted from the other end of the optical waveguide is received, and the transmission characteristic of the optical loss filter obtained based on the received light is monitored while performing irradiation with ultraviolet light. By this means, the prescribed transmission characteristic can be obtained easily and with still better precision.

By means of the above method of manufacturing an optical loss filter, the optical loss filter of this invention can be manufactured.

The optical loss filter of this invention is an optical loss filter formed in an optical waveguide having a core with a prescribed refractive index, and used within a prescribed usage wavelength band. The optical loss filter comprises a first long-period grating, having a refractive index fluctuation width provided in the core as the first fluctuation width, a refractive index fluctuation period as the first period, and having the wavelength at which a maximum

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value of the attenuation due to coupling of the core

mode with a cladding mode is obtained as the first

wavelength; a second long-period grating, provided in

the core at a prescribed distance from the first long-

5   period grating, having a refractive index fluctuation

width as the second fluctuation width, a refractive

index fluctuation period as the second period, and

having the wavelength at which a maximum value of the

attenuation due to coupling of the core mode with a

10   cladding mode is obtained as the second wavelength;

and, a phase-shifting member, formed by irradiating the

core between the first and second long-period gratings

with ultraviolet light, after formation of the first

and second long-period gratings, and which causes a

15   change in the amount of phase rotation of the core

mode.

     In this optical loss filter, the prescribed

transmission characteristics are obtained easily and

with good precision. Further, the number of long-period

20   gratings formed can be reduced, so that manufacturing

in compact form is possible.

     The optical loss filter of this invention has the

relation

$$0 < \Delta N \leq \lambda / \Delta L$$

25   where λ is an arbitrary wavelength within a

prescribed usage wavelength band, ΔL is the length of

the optical waveguide in which the phase-shifting member is formed, and ΔN is the amount of change before and after the change in the refractive index of the core of the optical waveguide.

In the optical loss filter of this invention, the first period and second period, and the first fluctuation width and second fluctuation width, are respectively equal. Or, the first period and the second period are equal, but the first fluctuation width and the second fluctuation width are different. Or, the first fluctuation width and second fluctuation width are equal, but the first period and second period are different. Or, the first fluctuation width and second fluctuation width, and the first period and second period, respectively are different.

In the optical loss filter of this invention, it is preferable that the order of the core mode and the coupled cladding mode in the prescribed usage wavelength band coincide in each of the first and second long-period gratings. If the order of the core mode and of the coupled cladding mode coincide, the transmission characteristics of the individual long-period gratings change according to differences in the phase rotation amounts of the core mode and cladding mode between them, so that more diverse characteristics can be obtained.

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In the optical loss filter of this invention, it is preferable that one or more third long-period gratings be comprised in the optical waveguide, and that the refractive index fluctuation width of this third long-period grating be different from the refractive index fluctuation width of the first and second long-period gratings. It is also preferable that the refractive index fluctuation period of the third long-period grating be different from the refractive index fluctuation period of the first and second long-period gratings. By this means, further diversification of the transmission characteristics of the optical loss filter is possible.

In the optical loss filter of this invention, it is preferable that the third long-period grating be such that the order of the cladding mode coupling with the core mode within the prescribed usage wavelength band be different from that of the cladding mode coupling with the core mode in the first and second long-period gratings. By this means, the transmission characteristic of the optical loss filter is expressed as the sum, in decibel units, of the transmission characteristic obtained by the combination of the first and second long-period gratings, and the transmission characteristic of the third long-period grating, so that a prescribed characteristic can be easily

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synthesized.

The present invention can be fully understood through the following detailed explanation and the attached drawings. These are merely examples, and

5   should not be regarded as limiting the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a figure which explains the configuration of an optical loss filter comprising two

10 long-period gratings (in the case in which the orders of the core mode and the coupled cladding mode in each of the long-period gratings coincide);

Fig. 1B is a figure which explains the changes in the complex amplitude of the core mode and cladding

15 mode in each of the long-period gratings shown in Fig. 1A;

Fig. 2 is a graph showing the transmission characteristic of the optical loss filter shown in Fig. 1A and Fig. 1B;

20 Fig. 3A is a figure which explains the configuration of an optical loss filter comprising two long-period gratings (in the case in which the orders of the core mode and the coupled cladding mode in each of the long-period gratings differ);

25 Fig. 3B is a figure which explains the changes in the complex amplitude of the core mode and cladding

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mode in each of the long-period gratings shown in Fig. 3A;

Fig. 4 is a graph showing the transmission characteristic of the optical loss filter shown in Fig. 3;

Fig. 5A is an explanatory figure which explains a method of manufacturing an optical loss filter;

Fig. 5B is a figure showing the refractive index profile of a manufactured optical loss filter;

Fig. 6A and Fig. 6B are figures which explain the method of manufacturing an optical loss filter in a first embodiment of this invention;

Fig. 7 is a graph showing the transmission characteristics of the optical loss filter of the first embodiment;

Fig. 8A, Fig. 8B, and Fig. 8C are figures showing examples of the configuration of an optical loss filter of the first embodiment;

Fig. 9 is a graph showing the transmission characteristics corresponding to each of the optical loss filters shown in Fig. 8A, Fig. 8B, and Fig. 8C;

Fig. 10A and Fig. 10B are figures which explain the method of manufacturing an optical loss filter in a second embodiment of this invention;

Fig. 11 is a graph showing the transmission characteristics of an optical loss filter of the second

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embodiment;

Fig. 12 is a figure showing the configuration of an optical loss filter of the second embodiment;

Fig. 13 is a graph showing the transmission characteristics of the optical loss filter shown in Fig. 12;

Fig. 14 is a figure showing the configuration of a long-period grating comprised by the optical loss filter in a third embodiment;

Fig. 15 is a graph showing the transmission characteristic of the long-period grating shown in Fig. 14;

Fig. 16 is a graph showing the configuration of an optical loss filter of the third embodiment of this invention;

Fig. 17 is a graph showing the transmission characteristic of the optical loss filter shown in Fig. 16;

Fig. 18 is a graph showing the gain characteristic when an optical loss filter of this invention is applied as a gain equalizer of EDFA;

Fig. 19 is a figure showing the configuration of another optical loss filter of the third embodiment of this invention;

Fig. 20 is a graph showing a gain characteristic of EDFA; and,

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Fig. 21 is a graph showing one example of the transmission characteristic of a long-period grating.

BEST MODE FOR CARRYING OUT THE INVENTION

Below, preferred embodiments of the method of manufacturing an optical loss filter of this invention, and of an optical loss filter of this invention, are explained in detail, referring to the attached drawings. Elements which are the same in the drawings are assigned the same symbols, and redundant explanations are omitted.

Prior to explaining the method of manufacturing an optical loss filter and the optical loss filter of this invention, the transmission characteristic of an optical loss filter comprising two long-period gratings is explained.

The transmission characteristic of a long-period grating is determined by solving the following mode-coupling equation.

$$dA \, / \, dz + j\chi_{core} A + j\kappa^m B^m \cdot \exp(2j\delta^m z) = 0 \qquad (2)$$

$$dB^m \, / \, dz + j\chi^m_{clad}B^m + j\kappa^m A \cdot \exp(-2j\delta^m z) = 0 \qquad (3)$$

Here A is the core mode complex amplitude, B^m is the mth cladding mode complex amplitude, and j indicates the imaginary unit. χ_{core} is the change in propagation constant of the core mode due to rising refractive index, χ^m_{clad} is the change in propagation constant of the mth cladding mode due to rising constant of the mth cladding mode due to rising

refractive index, and κ^m is the coupling constant between the core mode and the mth cladding mode.

If Λ is the grating period, β_{core} is the core mode propagation constant, and β^m_{clad} is the mth cladding

5   mode propagation constant, then δ^m is expressed by

$$\delta^m = (\beta_{core} - \beta^m_{clad}) / 2 \qquad\qquad (4)$$

and is a parameter determined by the refractive index profile of the optical waveguide, for example, an optical fiber.

10   When the above differential equations (2) and (3) are solved for certain initial conditions, the transmission characteristic of the core mode resulting from the grating is given by $|A(L)/A(0)|^2$ (where L is the grating length). The solution of these equations

15   can be expressed as a matrix:

$$\begin{bmatrix} A(L) \\ B^m(L) \end{bmatrix} = M^m \begin{bmatrix} A(0) \\ B^m(0) \end{bmatrix} \qquad\qquad (5)$$

Here M^m is a matrix representing the coupling of the core mode and the mth cladding mode.

When one such long-period grating is formed in the

20   optical waveguide, the initial condition for the cladding mode can be written $B^m(0) = 0$ (the core mode initial condition is A(0)), so that $|A(L)/A(0)|^2$ can be written using a simple equation, and by modifying the length of the long-period grating, the period, and the

25   amplitude of the refractive index change, the loss

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wavelength, loss amount, and half-width can be adjusted
to prescribed values.

Fig. 1A is a figure showing in summary the
construction of an optical loss filter provided with
5   two long-period gratings. In this figure, the optical
loss filter 100 is an optical fiber serving as an
optical waveguide and comprising a core 110 doped with
GeO_2, and cladding 120 provided on the periphery of the
core 110. The two long-period gratings formed in the
10   core 110 have cladding modes, coupled with the core
mode, the orders of which coincide.

Specifically, in the optical fiber 100 of Fig. 1A
are provided two long-period gratings LPG-a, LPG-b, in
which the cladding mode orders (mth order) coupled with
15   the core mode in the longitudinal direction coincide.
The long-period grating LPG-a has a refractive index
fluctuation period (grating period) Λ_a of 507 μm, a
grating length L_a of 30 mm, and a propagation matrix
$M_a{}^m$. The long-period grating LPG-b has a refractive
20   index fluctuation period Λ_b of 495 μm, grating length
L_b of 40 mm, and propagation matrix $M_b{}^m$. Fig. 2 is a
graph showing the transmission characteristics of the
optical loss filter 100 shown in Fig. 1A.

In Fig. 1A, the complex amplitude of the core mode
25   with initial value $A_b(0)$ (the initial value $B_a{}^m(0)$ of
the mth cladding mode is zero) in the first-stage long-

period grating LPG-b is $A_b(L_b)$, and the complex amplitude of the mth cladding mode is $B_b^m(L_b)$. $A_b(L_b)$ is the initial value of the core mode in the second-stage grating LPG-a, while $B_b^m(L_b)$ is equal to the initial

5   value $B_a^m(0)$ of the mth cladding mode in the second-stage long-period grating LPG-a. $B_a^m(0)$ is not zero, so that ultimately the mth cladding mode differs from the mth cladding mode independently coupled in the first-stage long-period grating LPG-a (see Fig. 1B). In other

10   words, the transmission characteristics of each of the long-period gratings LPG-a and LPG-b differ from the respective transmission characteristics for the case in which each exists independently.

In this way, when there is an interdependence

15   between the first-stage grating LPG-b and the second-stage grating LPG-a, the transmission characteristic L3 for the optical loss filter 100 as a whole cannot be represented as the sum in decibel units of the transmission characteristics L1, L2 when the initial

20   value of the mth cladding modes in each of the long-period gratings LPG-a, LPG-b is zero, as shown in Fig. 2. In other words, even if long-period gratings are combined which cause mode coupling in a prescribed band between the same-order (mth order) clade mode and core

25   mode, the transmission characteristic is not the sum of the individual transmission characteristics of each

long-period grating; instead, a transmission characteristic with numerous changes is obtained.

Fig. 3A is a figure showing in summary the construction of another optical loss filter in which two long-period gratings are provided. In this figure, the optical loss filter 200 is an optical fiber serving as an optical waveguide and comprising a core 210 doped with GeO_2, and a cladding 220 provided on the periphery of the core 110. The two long-period gratings formed within the core 210 have cladding modes of different orders coupled with the core mode.

Specifically, in the optical fiber 200 of Fig. 3A, two long-period gratings LPG-a, LPG-c are provided, with different cladding mode orders coupled with the core mode in the longitudinal direction. Similarly to the second-stage long-period grating in Fig. 1A, the long-period grating LPG-a has a refractive index fluctuation period (grating period) Λ_a of 507 μm and a grating length L_a of 30 mm; the propagation matrix is M_a^m. On the other hand, the long-period grating LPG-c has a refractive index fluctuation period Λ_c of 564 μm and a grating length L_c of 32 mm; the propagation matrix is M_c^n. Fig. 4 is a graph showing the transmission characteristic of the optical loss filter 200 shown in Fig. 3A.

In the long-period gratings LPG-a and LPG-c of

this optical loss filter 200, the orders of the
cladding modes which can couple with the propagation
mode in the core in the wavelength band shown in Fig. 4
are different (the nth and mth orders). Under this

5   condition, an nth cladding mode $B_c^n(L_c)$ occurs in the
first-stage long-period grating LPG-c (the complex
amplitude of the core mode with initial value $A_c(0)$ is
$A_c(L_c)$), but almost no coupling of this cladding mode
occurs in the second-stage grating LPG-a, and so there

10   is no effect on the characteristics of LPG-a. Hence the
initial value of the core mode for the second-stage
grating LPG-a can be set to, and the initial value of
the mth cladding mode B_a^m can be set equal to zero.
Hence the complex amplitude finally obtained for the

15   core mode, and the complex amplitude for the mth
cladding mode, are equal in the case in which the
second-stage long-period grating LPG-a exists
independently (see Fig. 3B).

      That is, by having the order of the cladding mode

20   which can couple with the propagation mode in the core
within the prescribed band be different for the two
long-period gratings, the transmission characteristic
L3 for the entire optical loss filter 200 can be
expressed as the sum in decibel units of the

25   transmission characteristics L1, L2 of the two long-
period gratings LPG-a, LPG-c, as shown in Fig. 4.

Hence it is required that the long-period gratings
employed in the optical loss filter of this embodiment
have two or more period structures with different
refractive index periods, in order that cladding modes

5   with different orders in the prescribed wavelength band
and core modes are coupled. They are formed such that
transmission characteristics of each of the long-period
gratings are in a relation of addition or subtraction
(in the case of decibel units) with the overall

10   transmission characteristics. Next, a prescribed method
is used to adjust the loss wavelength and the amount of
attenuation at that wavelength for each of the long-
period gratings, and by combining the adjusted long-
period gratings, it is possible to manufacture an

15   optical loss filter with the desired transmission
characteristic. Conversely, the transmission
characteristics of the optical loss filter to be
manufactured can be set at first, and a plurality of
long-period gratings equivalent to this transmission

20   characteristic can be combined to obtain the desired
optical loss filter.

Next, a method of manufacturing an optical loss
filter with the above construction is explained. Fig.
5A is a figure illustrating a method of manufacturing a

25   long-period grating comprised by an optical loss
filter; Fig. 5B is a graph showing the refractive index

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profile of each filter region (regions in which long-period gratings are formed) in an optical loss filter manufactured by the method of Fig. 5A.

In order to obtain an optical loss filter, an optical fiber 300 is prepared as an optical waveguide, comprising a core 310 doped with GeO_2, and cladding 320 provided on the periphery of the core 310. In Fig. 5A, an intensity modulating mask 32 is provided on the optical fiber 300 to modulate the intensity of ultraviolet light in the longitudinal direction of the optical fiber 300. This intensity modulating mask 32 comprises a silica glass plate 33, and a pattern 34, provided at prescribed intervals on the silica glass plate 33, to block ultraviolet light. Also, an ultraviolet ray reflecting mirror 31 is arranged so as to guide ultraviolet light 30 emitted from the light source 37 to the intensity modulating mask 32, so as to sandwich the intensity modulating mask 32 together with the optical fiber 300. This ultraviolet ray reflecting mirror 31 can be moved along the core 310 of the optical fiber 300 (along the direction indicated by the arrow S1 in the figure).

A light source 50 of semiconductor laser which emits measurement light in the usage wavelength band is connected to one end of the optical fiber 300; at the other end of the optical fiber 300 are arranged an

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optical spectrum analyzer 51 which detects the
wavelength and the power at that wavelength of
measurement light which has passed through the
prescribed region, data processing means 52 having a

5   memory to store electrical signal data from the optical
spectrum analyzer 51 and a CPU to perform prescribed
computation processing, and an image display device 53
to display electrical signal data from the data
processing means 52.

10   The optical fiber 300 employs silica glass as the
main component; the core 310 comprises germanium, which
raises the refractive index. This germanium is known as
a material which is sensitive to ultraviolet light at
wavelengths near 248 µm or 193 µm. That is, silica

15   glass comprising germanium has the property by which,
when irradiated with ultraviolet light at the above
wavelengths, the refractive index rises in the
irradiated portions. For this reason, the light from an
excimer laser in the 248 µm wavelength band is used as

20   the ultraviolet light 30 for irradiation of the optical
fiber 300. In order to improve the efficiency of the
refractive index increase due to ultraviolet
irradiation, the optical fiber 300 is doped with
hydrogen at 100 atmospheres.

25   The intensity modulating mask 32 has a plurality
of stripe-shaped chromium layers 34, evaporation-

deposited at equal intervals onto the surface of the transparent silica glass plate 33. This chromium layer 34 blocks the ultraviolet beam 30. Hence on the chromium evaporation-deposited surface of the silica glass plate 33, light-blocking portions (that is, chromium layers) and light-transmitting portions (the glass surface positioned between chromium layers) are arranged in an alternating grid. Consequently, the ultraviolet light which has passed through the intensity modulating mask 32 is incident in grid shape at equal intervals on the optical fiber 300. This irradiated light is incident on the core 310 comprising germanium, a photosensitive material, and induces a refractive index change in the core 310. By this means, a plurality of sites the refractive index of which has risen locally are arranged in the core 310 of the optical fiber 300 at equal intervals. By thus inducing a periodic rise in the refractive index of the core 310, a long-period grating is formed having the desired transmission characteristic in the desired region (the grating formation region) of the core 310.

In this optical loss filter, a first long-period grating is formed in the core 310 by irradiating the region for grating formation 310a which is to become the filter region with an ultraviolet beam through an intensity modulating mask 32, as shown in Fig. 5A. Fig.

5B shows the refractive index profile 222 of the first long-period grating formed in this way. In Fig. 5B, the refractive index profile 111 of the cladding 320 in the region of formation of the first long-period grating is also shown.

Next, the position of the ultraviolet ray reflecting mirror 31 is shifted, and the grating formation region 310b, at a prescribed distance from the grating formation region 310a, is irradiated with an ultraviolet beam to form the second long-period grating in the core 310.

When forming the first and second long-period gratings, measurement light from the light source 50 is input from one end of the optical fiber 300, and the measurement light emitted from the other end of the optical fiber 300 is received by an optical spectrum analyzer 51. It is preferable that electrical signal data from the spectrum analyzer 51 be processed by the data processing means 52, and that electrical signal data from the data processing means 52 be displayed on an image display device 53, to monitor the transmission characteristic of the optical loss filter.

First Embodiment

First, a method of manufacturing an optical loss filter of the first embodiment, and the optical loss filter manufactured by this method, are explained. In

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the method of manufacturing an optical loss filter of
this embodiment, a method similar to that described
above is used to form two long-period gratings, and
then the interval between these two long-period
5   gratings is irradiated with ultraviolet light to form a
phase-shifting member.

Fig. 6A is a figure showing a method of
manufacturing two long-period gratings; Fig. 6B is a
figure showing a method of irradiating the interval
10   between the long-period gratings with ultraviolet
light. In Fig. 6A and Fig. 6B, only the core 11 of the
optical fiber 10 comprised by the optical loss filter
is shown, without the cladding, in order to avoid
complexity in the drawing; but similarly to the optical
15   fiber 300 shown in Fig. 5A, the optical fiber has a
structure comprising a core doped with GeO_2, and
cladding provided on the core periphery. In the
following drawings also, the cladding is similarly
omitted in order to avoid complexity in the drawings.
20   First, as shown in Fig. 6A, by irradiating the
optical fiber 10 with an ultraviolet beam 30 through an
intensity modulating mask 32 while scanning a
reflecting mirror 31, two long-period gratings LPG-d,
LPG-e are formed, with an intervening interval 20 of 5
25   mm, in the core 11 of the optical fiber 10 (first
process). The long-period grating LPG-d has a grating

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length Ld of 15 mm and refractive index fluctuation

period Λ_d of 345 μm. The long-period grating LPG-e has

a grating length Le of 15 mm, and a refractive index

fluctuation period Λ_e of 350 μm. At this time,

5   measurement light from a light source 50 is input from

one end of the optical fiber 10, and the measurement

light emitted from the other end of the optical fiber

10 is received by an optical spectrum analyzer 51. It

is preferable that electrical signal data from the

10   spectrum analyzer 51 be processed by data processing

means 52, and electrical signal data from the data

processing means 52 be displayed on an image display

device 53, to monitor the transmission characteristic

at this stage.

15   Next, as shown in Fig. 6B, after removing the

intensity modulating mask 32, the reflecting mirror 31

is scanned, the optical fiber 10 in the interval

portion 20 between the long-period grating LPG-d and

the long-period grating LPG-e is irradiated with

20   ultraviolet light, and the refractive index of this

portion is raised (second process). Here the order of

the cladding mode contributing to coupling with the

core mode is made to coincide with the order of the

core mode within the same wavelength band. Through

25   this, the desired transmission characteristic can be

easily obtained.

When irradiating the interval portion 20 with
ultraviolet light, measurement light from the light
source 50 is input from one end of the optical fiber
10, and the measurement light emitted from the other
5   end of the optical fiber 10 is received by the optical
spectrum analyzer 51. It is preferable that electrical
signal data from the spectrum analyzer 51 be processed
by the data processing means 52, and electrical signal
data from the data processing means 52 be displayed on
10   the image display device 53, to monitor the
transmission characteristic of the optical loss filter.
When the optical loss filter transmission
characteristic displayed on the image display device 53
substantially coincides with the desired
15   characteristic, irradiation of the interval portion 20
with ultraviolet light is halted. By this means, an
optical loss filter having the desired transmission
characteristic can be manufactured easily and with good
precision.
20   Fig. 7 is a graph showing the transmission
characteristic of an optical loss filter obtained by
the above method. When the interval portion 20 of the
optical fiber 10 between the two long-period gratings
LPG-d and LPG-e is irradiated with ultraviolet light,
25   the refractive index of the core of the optical fiber
10 increases, so that the phase velocity of the core

mode propagating in this portion changes, and the effective optical path length between the two gratings changes. Hence the wavelength of maximum attenuation changes with the amount of ultraviolet irradiation, as

5   indicated by the solid line L1, dotted line L2 and dashed line L3, and various transmission characteristics can be obtained. The arrow S2 in Fig. 7 indicates the direction of increasing ultraviolet irradiation amount.

10   In such a phase-shifting long-period grating in which the core mode phase is shifted in the interval 20 between two long-period gratings, the difference in the amount of phase rotation between the core and cladding modes in this interval portion 20 results in the same

15   transmission characteristic for every change by 2π, so that the desired characteristic can be obtained for a value of the quantity (difference in phase rotation after ultraviolet irradiation) - (difference in phase rotation before ultraviolet irradiation) between 0 and

20   2π. That is, the relation

$$0 < (\beta_{core}'\Delta L - \beta_{cladding}'\Delta L) - (\beta_{core}\Delta L - \beta_{cladding}\Delta L) \leq 2\pi \qquad (6)$$

should be satisfied. Here ΔL is the distance between the two long-period gratings, β_{core} and $\beta_{cladding}$

25   are respectively the propagation constants at the usage wavelength λ of the core mode and cladding mode before

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irradiation with ultraviolet light, and β_{core}' and $\beta_{cladding}'$ are respectively the propagation constants at the usage wavelength λ of the core mode and cladding mode after irradiation with ultraviolet light. Further, by using

$$\beta_{cladding}' \fallingdotseq \beta_{cladding} \qquad (7)$$

$$\beta_{core}' \fallingdotseq (2\pi/\lambda) n_{core} \qquad (8)$$

the following relation is obtained.

$$0 < (n_{core}' - n_{core}) \le \lambda/\Delta L \qquad (9)$$

Here n_{core} is the core refractive index before ultraviolet irradiation, and n_{core}' is the core refractive index after ultraviolet irradiation.

As explained above, by irradiating the interval portion 20 of the optical fiber with ultraviolet light, the core refractive index changes, and the amount of phase rotation of the core mode changes; hence this is called a "phase-shifting member".

Next, an example of the configuration of another optical loss filter, formed by the same method as that described above, is explained. First, the reflecting mirror 31 shown in Fig. 6A is scanned, and two types of long-period grating are formed at a prescribed interval in the core 11 of the optical fiber 10, through the intensity modulating mask 32. Then, as shown in Fig. 6B, after the intensity modulating mask 32 is removed, the interval portion 20 of the optical fiber 10 is

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uniformly irradiated with ultraviolet light, to produce the optical loss filter.

Figs. 8A to 8C are figures showing examples of the configuration of optical loss filters obtained in this way. In the optical loss filter shown in Fig. 8A, a long-period grating LPG-d_1 with a grating length Ld1 of 22 mm and refractive index fluctuation period Λ_{d1} of 343.5 μm, and a long-period grading LPG-e_1 with a grating length Le1 of 7 mm and refractive index fluctuation period Λ_{e1} of 352.5 μm are provided in the axial direction of the optical fiber 10, separated by an interval Ls of 5 mm. This interval portion 20 is irradiated with ultraviolet light to provide a phase-shifting member. The refractive index fluctuation widths of the long-period gratings LPG-d_1 and LPG-e_1 are equal.

In the optical loss filter shown in Fig. 8B, a long-period grating LPG-d_2 with a grating length Ld2 of 20 mm and refractive index fluctuation period Λ_{d2} of 348 μm, and a long-period grating LPG-e_2 with a grating length Le2 of 7 mm and refractive index fluctuation period Λ_{e2} of 348 μm, are provided in the axial direction of the optical fiber 10, separated by an interval 20 of 5 mm. This interval portion 20 is irradiated with ultraviolet light to provide a phase-shifting member. The refractive index fluctuation

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widths of the long-period gratings LPG-d_2 and LPG-e_2 are different.

In the optical loss filter shown in Fig. 8C, a long-period grating LPG-d with a grating length Ld3 of 20 mm and refractive index fluctuation period Λ_{d3} of 347 μm, and a long-period grating LPG-e_3 with a grating length Le3 of 7 mm and refractive index fluctuation period Λ_{e3} of 351 μm, are provided in the axial direction of the optical fiber 10, separated by an interval 20 of 5 mm. This interval portion 20 is irradiated with ultraviolet light to provide a phase-shifting member. The refractive index fluctuation widths of the long-period gratings LPG-d_3 and LPG-e_3 are different.

Fig. 9 is a graph showing the transmission characteristics of each of the above optical loss filters. The dashed line L1 is an example of the transmission characteristic of an optical loss filter in which the lengths and the refractive index fluctuation periods of the two long-period gratings are different, and the refractive index fluctuation widths are equal, as shown in Fig. 8A. The dotted line L2 is an example of the transmission characteristic of an optical loss filter in which the lengths and refractive index fluctuation widths of the two long-period gratings are different, and the refractive index

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fluctuation periods are equal, as shown in Fig. 8B. The solid line L3 is an example of the transmission characteristic of an optical loss filter in which the lengths, refractive index fluctuation widths, and refractive index fluctuation periods of the two long-period gratings are different, as shown in Fig. 8C.

Thus in the method of manufacturing an optical loss filter of this embodiment, by irradiating the interval portion 20 of the optical fiber with ultraviolet light, the refractive index of the core 11 can be changed substantially continuously, so that an optical loss filter having a highly precise transmission characteristic can be easily obtained. Because the number of gratings can be made small, manufacture in compact form is possible.

Second Embodiment

In this embodiment, a method of manufacturing an optical loss filter obtained by irradiating the intermediate portion of a single long-period grating with ultraviolet light, and the optical loss filter manufactured by this method, are explained. Fig. 10A is a figure which shows a method of manufacturing a long-period grating; Fig. 10B is a figure showing a method of irradiating the intermediate portion of the long-period grating with ultraviolet light.

First, as shown in Fig. 10A, the reflecting mirror

31 is scanned, and a long-period grating is formed in the core of the optical fiber 10 through an intensity modulating mask 32 (first process). This long-period grating LPG-f has a grating length Lf of 30 mm and refractive index fluctuation period Λ_f of 350 μm. Then, as shown in Fig. 10B, after removing the intensity modulating mask 32, the intermediate part 21 in the center 5 mm of the long-period grating LPG-f, excluding both ends, is irradiated uniformly with ultraviolet light by scanning the reflecting mirror 31 (second process).

When irradiating the intermediate portion 21 with ultraviolet light, measurement light from a light source 50 is input from one end of the optical fiber 10, and the measurement light emitted from the other end of the optical fiber 10 is received by the optical spectrum analyzer 51. It is preferable that electrical signal data from the spectrum analyzer 51 be processed by data processing means 52, and electrical signal data from the data processing means 52 be displayed on an image display device 53, to monitor the transmission characteristic of the optical loss filter. When the transmission characteristic of the optical loss filter displayed on the image display device 53 substantially coincides with the desired characteristic, the irradiation with ultraviolet light of the intermediate

portion 21 is halted. By this means, an optical loss filter having the desired transmission characteristic can easily be manufactured with good precision.

Fig. 11 is a graph showing the transmission characteristics of an optical loss filter obtained by the above method. When the intermediate portion 21 of the long-period grating LPG-f is irradiated with ultraviolet light, the refractive index of the intermediate portion 21 rises, the difference in phase-rotation amounts of core and cladding modes changes, and the effective optical path length of each mode in the refractive index fluctuating portion formed in the front and back of the irradiation position changes, so that the synthesized transmission characteristic has a maximum-attenuation wavelength shifted as shown by the solid line L1, dotted line L2, and dashed line L3 according to the amount of irradiation. The arrow S3 in Fig. 11 indicates the direction of increase of the amount of ultraviolet irradiation.

In such a phase-shifting long-period grating in which the phase in the intermediate portion 21 of one long-period grating is shifted, the transmission characteristic exhibited is substantially the same each time the difference in phase rotation amounts of core and cladding modes in the intermediate portion 21 changes by 2π, so that the desired characteristic can

be obtained for a value of the quantity (difference in phase rotation after ultraviolet irradiation) - (difference in phase rotation before ultraviolet irradiation) between 0 and 2π. On the other hand, because the equations (6) through (9) obtain, the relation

$$0 < (n_{mean}' - n_{mean}) \leq \lambda/\Delta L \tag{10}$$

is obtained. Here n_{mean} is the mean refractive index of the core of the refractive index fluctuation portion prior to irradiation with ultraviolet light, in a length ΔL of the intermediate portion 21, and is expressed by $n_{mean} = n_{min} + (n_{max} - n_{min})/2$, where the maximum refractive index and minimum refractive index of the refractive index fluctuation portion are n_{max} and n_{min} respectively. Also, n_{mean}' is the mean refractive index of the core of the refractive index fluctuation portion after irradiation with ultraviolet light in a length ΔL of the intermediate portion, and is expressed by $n_{mean}' = n_{min}' + (n_{max}' - n_{min}')/2$.

As explained above, the core refractive index changes on irradiation with ultraviolet light in the intermediate portion 21 of a long-period grating, and the amount of core mode phase rotation changes; hence this is called a "phase-shifting member" similarly to the interval portion 20 in the above-described first embodiment.

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In the optical loss filter of this embodiment, by
irradiating the intermediate portion 21 of one long-
period grating LPG-f, formed in advance, with
ultraviolet light, a long-period grating LPG-f' and a

5   long-period grating LPG-f'' are formed in front of and
behind the intermediate portion 21, respectively. In
this sense, the configuration is clearly different from
that of the optical loss filter of the first
embodiment, in which a first long-period grating and a

10   second long-period grating are formed separately, and a
phase-shifting member is formed in the interval portion
between them. However, from a different point of view,
it can be said that after a long-period grating LPG-f
is formed which comprises a long-period grating LPG-f'

15   and a long-period grating LPG-f'', the portion between
the long-period grating LPG-f' and the long-period
grating LPG-f'' is irradiated with ultraviolet light to
form a phase-shifting member. In this sense, the
optical loss filter of the first embodiment and the

20   optical loss filter of the second embodiment have
similar configurations.

Next, another optical loss filter formed by the
method described above is explained. First, the
reflecting mirror 31 is scanned, as shown in Fig. 10A,

25   to form a long-period grating the refractive index
fluctuation width and refractive index fluctuation

period of which are both constant in the core axis
direction of the optical fiber 10, by irradiation
through an intensity modulating mask 32. Next, after
removing the intensity modulating mask 32, the

5   reflecting mirror 31 is scanned to irradiate uniformly
with ultraviolet light an intermediate portion 21,
within the section in the axial direction of the core
in which the long-period grating is formed, and
excluding both ends of the section, as shown in Fig.

10   10B.

Fig. 12 is a figure showing an optical loss filter
obtained in this way. This optical loss filter is
fabricated by forming a long-period grating LPG-f1
having a grating length Lf1 of 29 mm in the optical

15   axis direction of the optical fiber 10 and a refractive
index fluctuation period Λ_{f1} of 345 μm, and then
irradiating with ultraviolet light a section from a
position at a distance Lf1' of 19 mm from one end
toward the other end of LPG-f1, to a position a

20   distance Ls1 of 5 mm further toward the other end.

Fig. 13 is a graph showing the transmission
characteristic of the optical loss filter shown in Fig.
12. When the intermediate portion 21 of one long-period
grating LPG-f1 is irradiated with ultraviolet light,

25   the intermediate portion 21 causes a phase shift with
respect to the refractive index fluctuating portion

positioned on either side, and a transmission characteristic is obtained having two attenuation maxima which change according to the phase shift.

In this way, when the intermediate portion 21 of a

5   long-period grating is irradiated with ultraviolet light, the core refractive index can be changed substantially continuously by adjusting the amount of ultraviolet irradiation; hence an optical loss filter having the desired transmission characteristic can be

10 obtained easily and with good precision.

Third Embodiment

In this embodiment, a method of manufacturing an optical loss filter which can be formed by combining the optical loss filter formed in the above-described

15 first embodiment or second embodiment with another long-period grating, to obtain a more complex transmission characteristic, as well as an optical loss filter manufactured by this method, are explained.

First, an optical fiber 10 comprising an optical

20 loss filter with the configuration shown in Fig. 12 is prepared. The long-period grating LPG-f comprised by this optical loss filter has a grating length $Lf1$ of 29 mm and a refractive index fluctuation period Λ_{f1} of 345 μm; a phase-shifting member is formed by irradiating

25 the intermediate portion 21 of the LPG-f1 with ultraviolet light. As shown in Fig. 13, the

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transmission characteristic of this optical loss filter

has two gentle loss peaks in the wavelength range 1540

to 1560 nm.

Next, the apparatus shown in Fig. 10A is used to

irradiate the optical fiber 10 with an ultraviolet beam

30 through an intensity modulating mask 32, to form a

new long-period grating LPG-p. Fig. 14 is a figure

showing the configuration of the new long-period

grating LPG-p formed in this way. This long-period

grating LPG-p has a grating length Lp of 31.5 mm and a

refractive index fluctuation period Λ_p of 394 μm. Fig.

15 is a graph showing the transmission characteristic

of the long-period grating LPG-p. The loss peak in the

transmission characteristic shown in Fig. 15 is formed

by the coupling of the core mode and the fifth cladding

mode.

Next, a method of manufacturing an optical loss

filter having a new transmission characteristic, formed

by combining an optical loss filter with the

construction shown in Fig. 12 and a long-period grating

LPG-p with the construction shown in Fig. 14, is

explained. When combining the two, the LGP-p formed in

one optical fiber can simply be connected by fusion to

the optical loss filter formed in another optical

fiber; but in this embodiment, as shown in Fig. 16, the

optical loss filter shown in Fig. 12 and the long-

period grating LPG-p shown in Fig. 14 are formed in a
single optical fiber 10, with an interval of length Lt
equal to 2 mm provided between them.

Because the cladding mode orders contributing to
5   coupling with the core mode are different in the same
wavelength band in the optical loss filter shown in
Fig. 12 and the long-period grating LPG-p shown in Fig.
14, each preserves its transmission characteristic even
when the two are brought into proximity. Hence the
10   transmission characteristic when the two are combined
is the value resulting from addition of the
transmission characteristics shown in Fig. 13 and Fig.
15, as shown in Fig. 17. In this way, in the method of
manufacturing an optical loss filter of this
15   embodiment, the optical loss filter shown in Fig. 12
and the long-period grating LPG-p shown in Fig. 14 can
be brought into proximity and arranged, so that the
optical loss filter can be manufactured in compact
form; and because the optical loss filter shown in Fig.
20   12 and the long-period grating LPG-p shown in Fig. 14
preserve their transmission characteristics, the
desired characteristic can easily be obtained with good
precision.

The new optical loss filter transmission
25   characteristic shown in Fig. 17 has a sharp loss peak
near 1530 nm, and two gentle loss peaks between 1540

and 1560 nm. On the other hand, as shown in Fig. 1, EDFA of 1.55 μm band has a sharp gain peak near 1530 nm, and two gentle gain peaks between 1540 and 1560 nm.

Hence when using an optical loss filter having the transmission characteristic shown in Fig. 17 (with the construction of Fig. 16) as the gain equalizer of an EDFA having the characteristic shown in Fig. 20, the sharp gain peak of the EDFA near 1530 nm is smoothed by the sharp loss peak of the transmission characteristic shown in Fig. 17. Also, the two gentle gain peaks between 1540 and 1560 nm shown in Fig. 20 are smoothed by the two gentle loss peaks in the transmission characteristic of Fig. 17. Fig. 18 shows the gain characteristic of an EDFA when using an optical loss filter with the construction of Fig. 16 as a gain equalizer. As shown in Fig. 18, an extremely flat gain characteristic is obtained over a wavelength band extending for approximately 39 nm.

In this embodiment, a case in which a new optical loss filter is configured by combining the optical loss filter of the second embodiment, having the construction shown in Fig. 12, and a long-period grating LPG-p, having the construction shown in Fig. 14, has been explained. In addition to this, a new optical loss filter may for example be configured by combining, as shown in Fig. 19, the optical loss filter

of the first embodiment, having the construction shown
in Fig. 8A, and a long-period grating LPG-p having the
construction shown in Fig. 14.

INDUSTRIAL APPLICABILITY

5   The method of manufacturing an optical loss filter
of this invention has a process for manufacturing a
long-period grating, and a process for irradiating the
core with ultraviolet light to change the refractive
index; because the amount of irradiation of the core
10   with ultraviolet light can be changed continuously, by
adjusting this amount of irradiation, a desired
transmission characteristic can be obtained easily and
with good precision. Also, a small number of long-
period gratings can be formed, so that manufacturing in
15   compact form is possible.

Because the optical loss filter is manufactured by
the method described above, a desired transmission
characteristic can be obtained easily and with good
precision. Moreover, because the number of long-period
20   gratings formed is small, [the optical loss filter] is
compact.

It is clear from the above explanation of this
invention that various modifications to this invention
are possible. These modifications should not be
25   regarded as deviating from the concept and scope of
this invention, and all improvements which are obvious

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to persons skilled in the art are included in the
following scope of claims.

CLAIMS

1.   A method of manufacturing an optical loss
filter in an optical waveguide having a core with a
prescribed refractive index, comprising:

5   a first process in which first and second long-
period gratings are formed in the axial direction of
the core having the photosensitivity of said optical
waveguide, providing a prescribed interval
therebetween; and,

10   a second process in which the core between said
first long-period grating and said second long-period
grating is irradiated with ultraviolet light.

2.   A method of manufacturing an optical loss
filter according to Claim 1, further comprising a third

15   process in which, prior to said first and second
processes, or after both said processes, one or more
third long-period gratings are formed.

3.   A method of manufacturing an optical loss
filter in an optical waveguide having a core with a

20   prescribed refractive index, comprising:

a first process in which a first long-period
grating, with constant refractive index fluctuation
width and refractive index fluctuation period, is
formed in the axial direction of the core having the

25   photosensitivity of said optical waveguide; and,

a second process in which a prescribed region

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within a section in the axial direction of the core in which said first long-period grating is formed, excluding both ends of the section, is irradiated with ultraviolet light.

5   4.   A method of manufacturing an optical loss filter according to Claim 3, further comprising a third process in which, prior to said first and second processes, or after both said processes, one or more second long-period gratings are formed.

10   5.   A method of manufacturing an optical loss filter according to any of Claims 1 through 4, wherein, in said second process, light in a prescribed usage wavelength band is input from one end of said optical waveguide, while light emitted from the other end of

15   the optical waveguide is received, and the transmission characteristic of the optical loss filter obtained based on the received light is monitored while performing irradiation with ultraviolet light.

   6.   An optical loss filter manufactured by a

20   method of manufacturing an optical loss filter according to any of Claims 1 through 5.

   7.   An optical loss filter, formed in an optical waveguide having a core with a prescribed refractive index, and used within a prescribed usage wavelength

25   band, comprising:

   a first long-period grating, provided in said

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core, the refractive index fluctuation width of which
is a first fluctuation width, the refractive index
fluctuation period of which is a first period, and
having a first wavelength at which the maximum value of
5   attenuation due to coupling of the core mode with a
cladding mode is obtained;

a second long-period grating, provided in said
core at a prescribed distance from said first long-
period grating, the refractive index fluctuation width
10   of which is a second fluctuation width, the refractive
index fluctuation period of which is a second period,
and having a second wavelength at which the maximum
value of attenuation due to coupling of the core mode
with a cladding mode is obtained; and,

15   a phase-shifting member, formed by irradiating the
core between said first and second long-period gratings
with ultraviolet light after formation of the first and
second long-period gratings, and which causes a change
in the amount of phase rotation of the core mode.

20   8.   The optical loss filter according to Claim 7,
having the relation

$$0 < \Delta N \leq \lambda/\Delta L$$

where λ is an arbitrary wavelength within said
prescribed usage wavelength band, ΔL is the length of
25   the optical waveguide in which said phase-shifting
member is formed, and ΔN is the amount of change

before and after the change in the refractive index of
the core of said optical waveguide.

9.   The optical loss filter according to Claim 7
or Claim 8, wherein said first period and said second
period, and said first fluctuation width and said
second fluctuation width, are respectively equal.

10.   The optical loss filter according to Claim 7
or Claim 8, wherein said first period and said second
period are equal, and said first fluctuation width and
said second fluctuation width are different.

11.   The optical loss filter according to Claim 7
or Claim 8, wherein said first fluctuation width and
said second fluctuation width are equal, and said first
period and said second period are different.

12.   The optical loss filter according to Claim 7
or Claim 8, wherein said first period and said second
period, and said first fluctuation width and said
second fluctuation width, are respectively different.

13.   The optical loss filter according to any of
Claims 7 through 12, wherein, within said prescribed
usage wavelength band, the order of said core mode and
the coupled cladding mode coincide in each of said
first and second long-period gratings.

14.   The optical loss filter according to any of
Claims 7 through 13, wherein one or more third long-
period gratings are further provided in said optical

waveguide, and the refractive index fluctuation width of the third long-period grating differs from the refractive index fluctuation width of said first and second long-period gratings.

5   15. The optical loss filter according to any of Claims 7 through 13, wherein one or more third long-period gratings are further provided in said optical waveguide, and the refractive index fluctuation period of the third long-period grating differs from the

10   refractive index fluctuation period of said first and second long-period gratings.

       16. The optical loss filter according to Claim 14 or Claim 15, wherein, in said third long-period grating, the order of said cladding mode coupling with

15   said core mode within said prescribed usage wavelength band differs from that of the cladding mode coupling with the core mode in said first and second long-period gratings.

ABSTRACT

The present invention relates to a method of manufacture of an optical loss filter, which is an optical component applicable to optical communications and related fields, comprising a long-period fiber grating to reduce the wavelength dependence of the gain of rare earth-doped fiber amplifiers in particular, as well as to an optical loss filter manufactured by this method. A method of manufacturing an optical loss filter of this invention is a method of manufacturing an optical loss filter in an optical waveguide having a core with a prescribed refractive index, comprising a first process in which first and second long-period gratings are formed in the axial direction of a core having the photosensitivity of the optical waveguide, providing a prescribed interval therebetween, and a second process in which the core between the first long-period grating and the second long-period grating is irradiated with ultraviolet light. In this method, because the amount of irradiation of the core with ultraviolet light can be changed continuously, by adjusting the amount of irradiation, an optical loss filter with a desired transmission characteristic can be obtained easily and with good precision. Also, the number of long-period gratings formed can be made small, so that manufacture in compact form is possible.
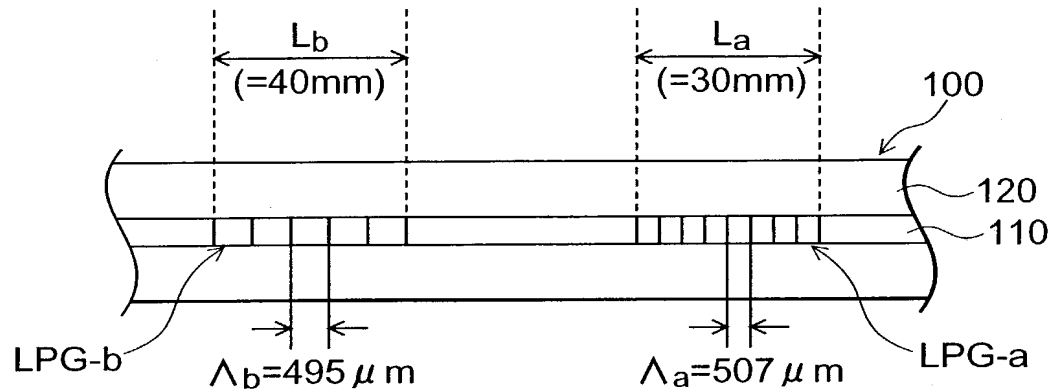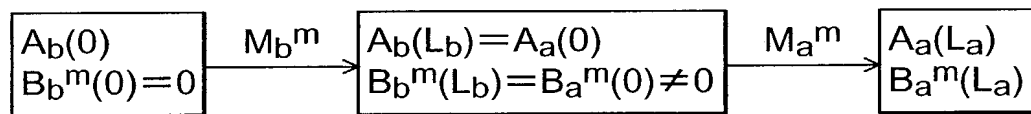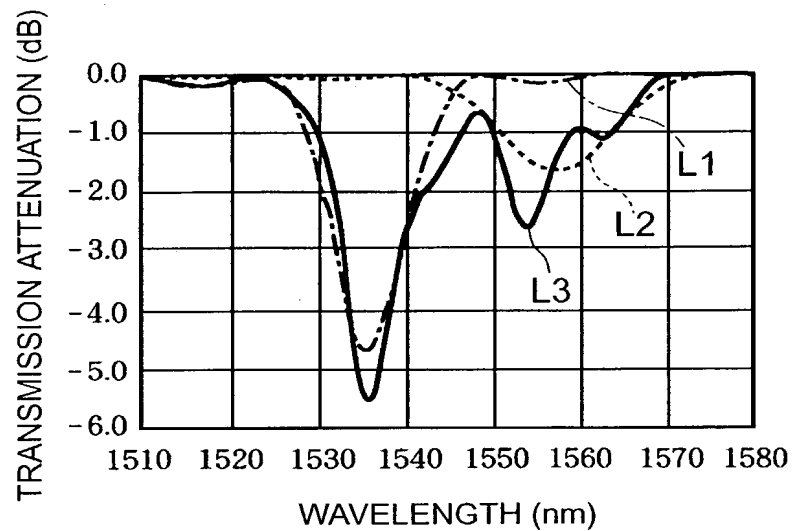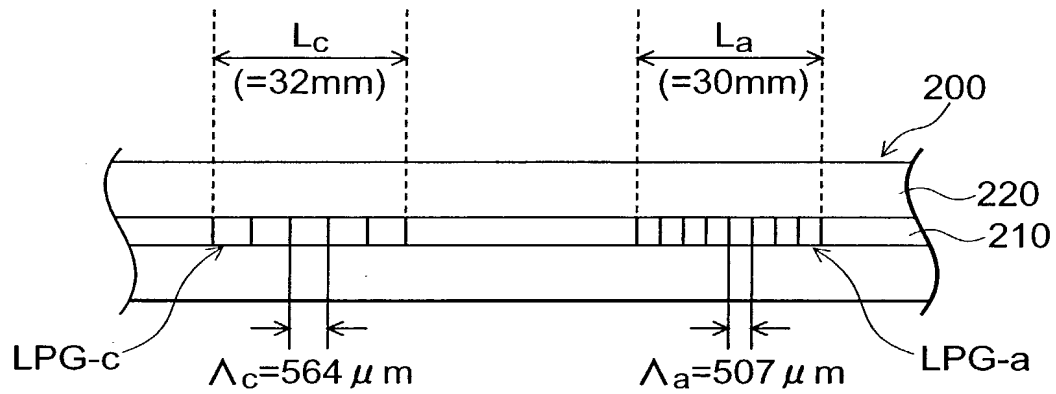
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Fig.1A

Fig.1B

Fig.2

Fig.3A

Fig.3B

Fig.4

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Fig.5A

Fig.5B

REFRACTIVE INDEX

POSITION IN FIBER
AXIS DIRECTION

Fig.6A

Fig.6B

Fig.7

Fig.8A

Λ_{d1}(=343.5μm)

LPG-d1

L_{d1}
(=22mm)

L_s
(=5mm)

Λ_{e1}(=352.5μm)

L_{e1}
(=7mm)

LPG-e1

Fig.8B

Λ_{d2}(=348μm)

LPG-d2

L_{d2}
(=20mm)

L_s
(=5mm)

Λ_{e2}(=348μm)

L_{e2}
(=7mm)

LPG-e2

Fig.8C

Λ_{d3}(=347μm)

LPG-d3

L_{d3}
(=20mm)

L_s
(=5mm)

Λ_{e3}(=351μm)

L_{e3}
(=7mm)

LPG-e3

Fig.9

Fig.10A

Fig.10B

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Fig.11

(Graph with axes: TRANSMITTANCE (dB) on vertical axis from 0 to -1, WAVELENGTH (nm) on horizontal axis from 1550 to 1600. Curves labeled L3, L2, S3, L1)

Fig.12

Λ$_{f1'}$(=345μm)   Λ$_{f1''}$(=345μm)   LPG-f1

L$_{f1'}$ (=19mm)   L$_{s1}$ (=5mm)   L$_{f1''}$ (=5mm)

L$_{f1}$
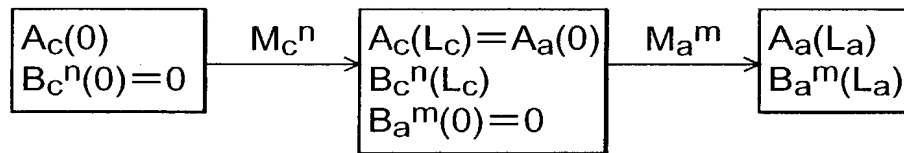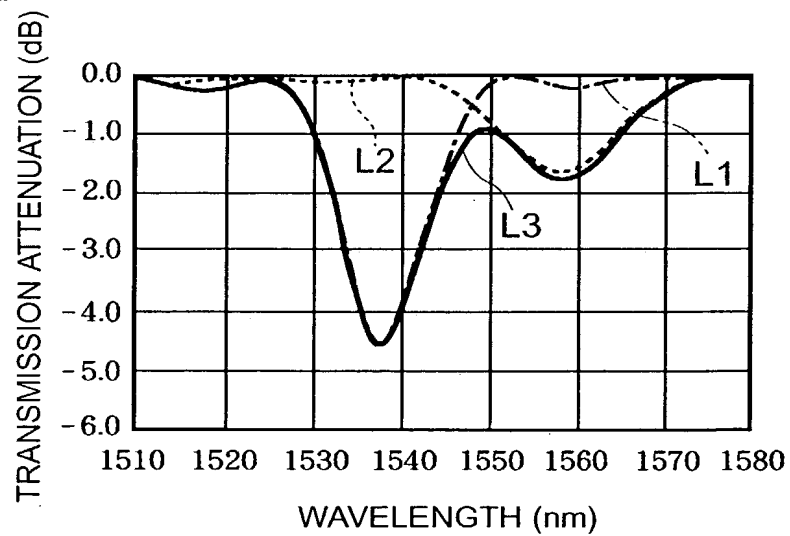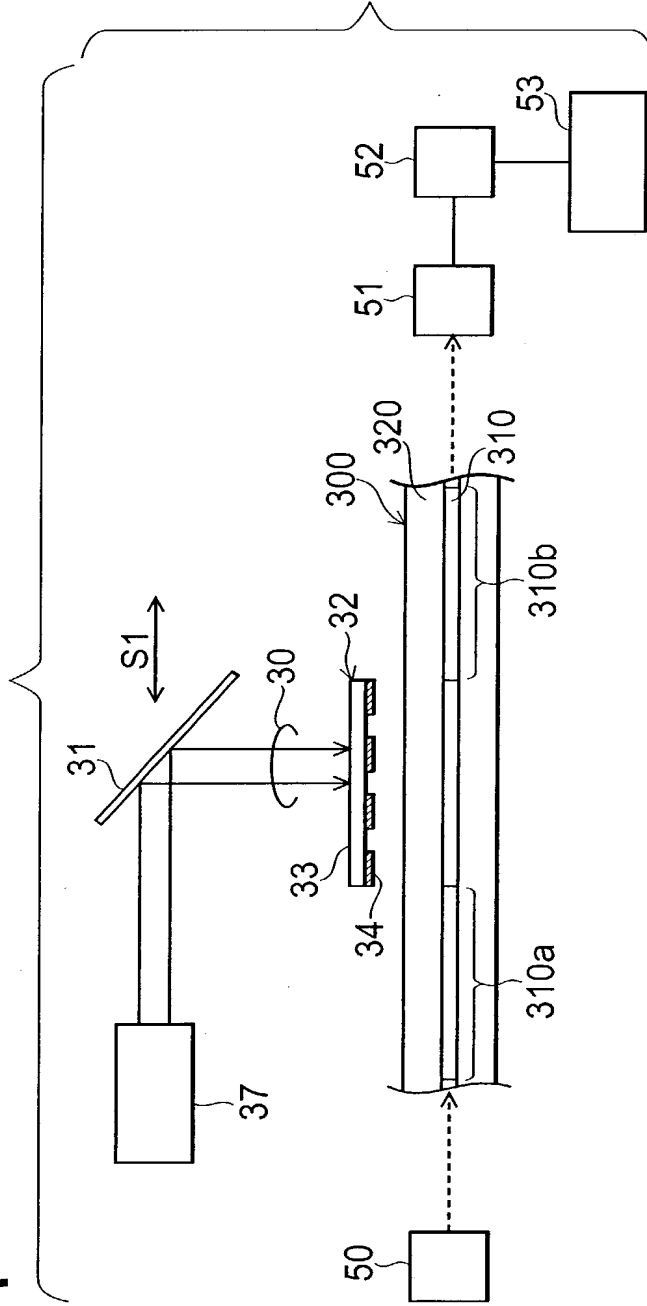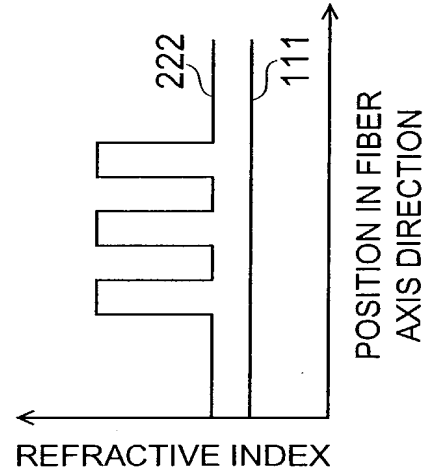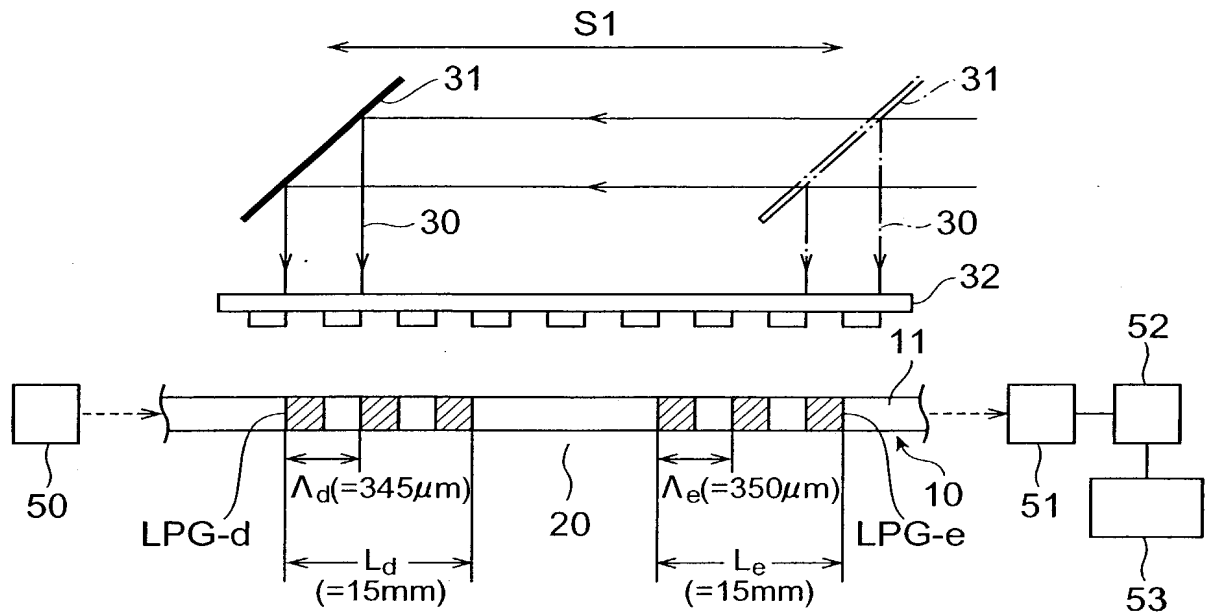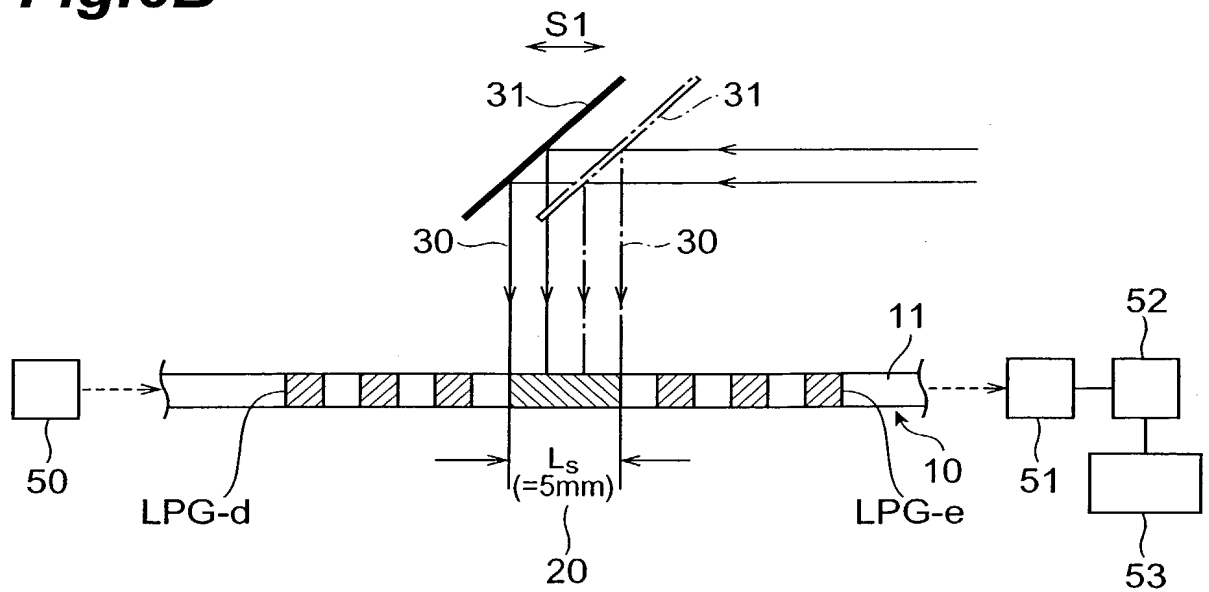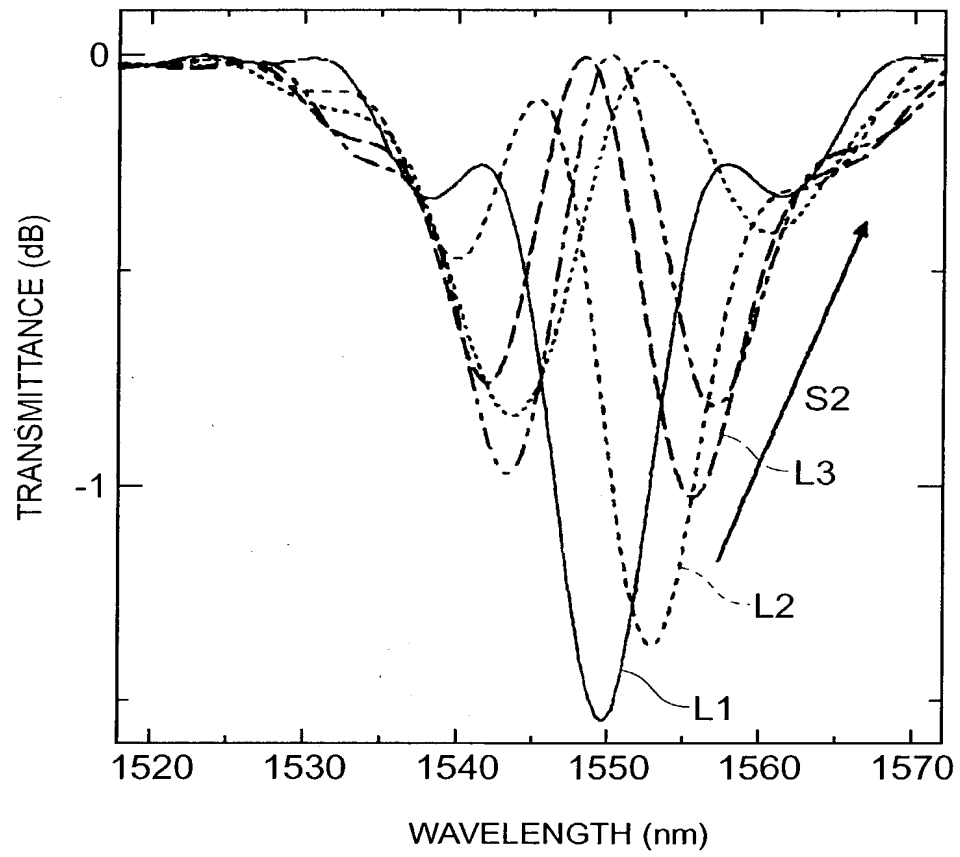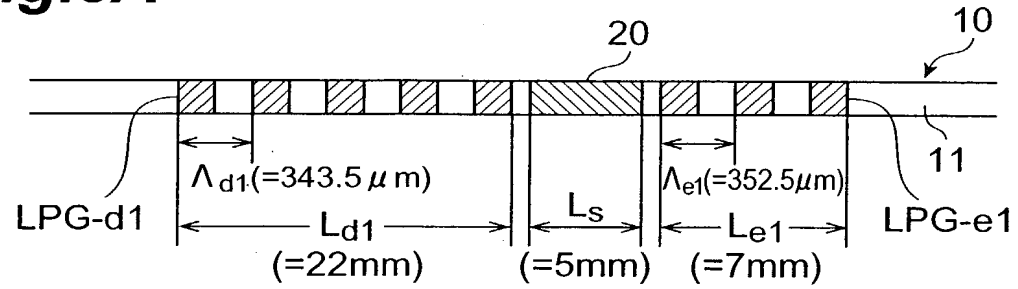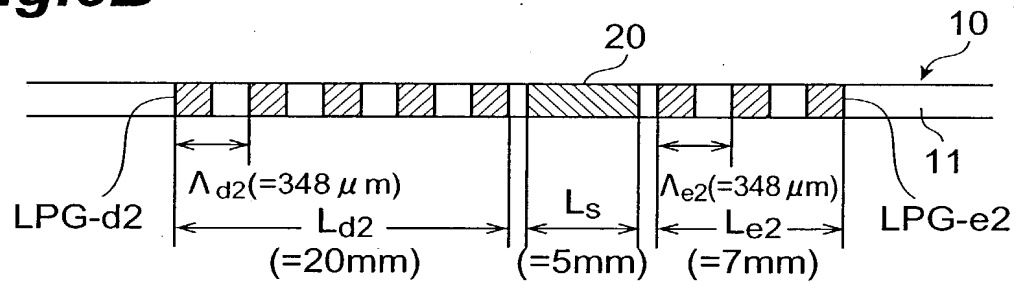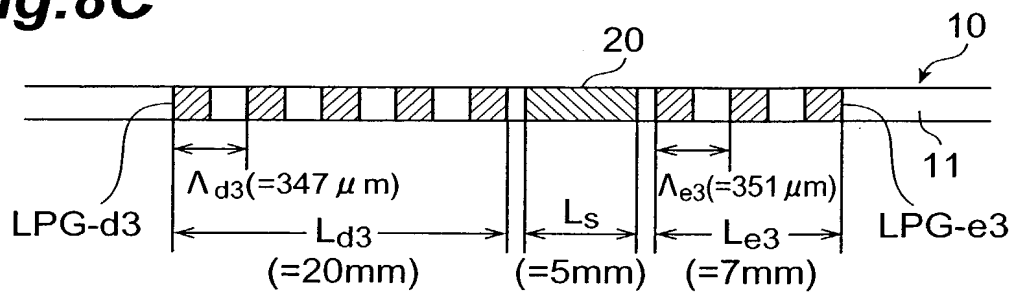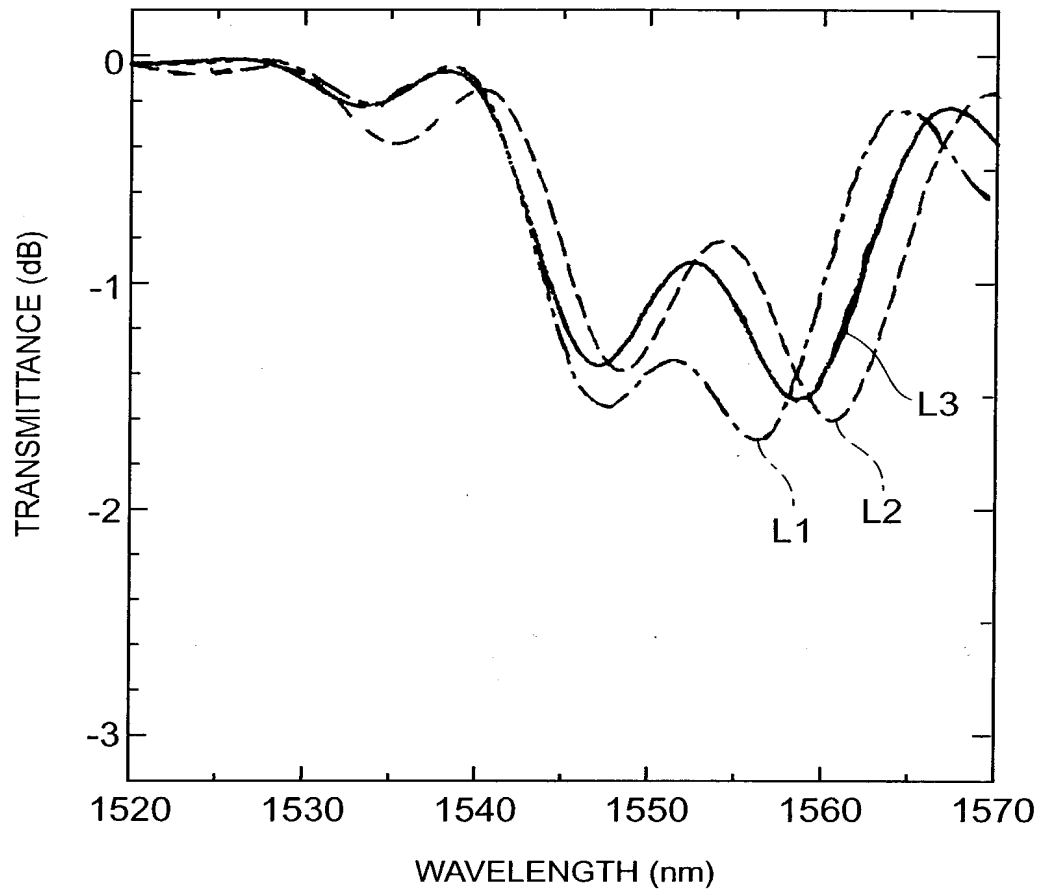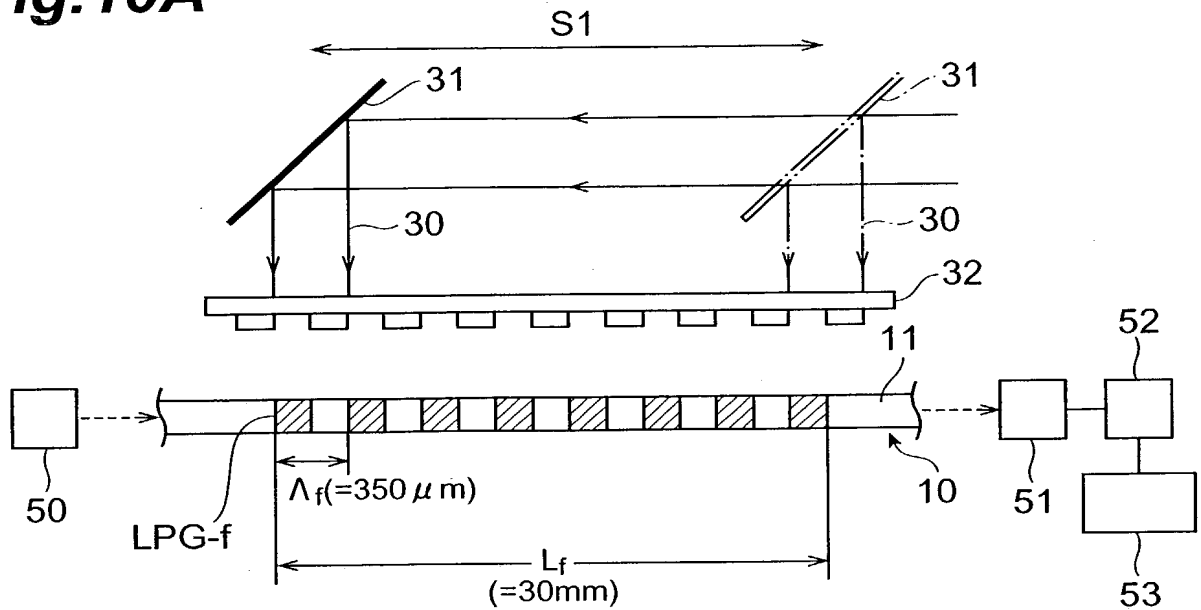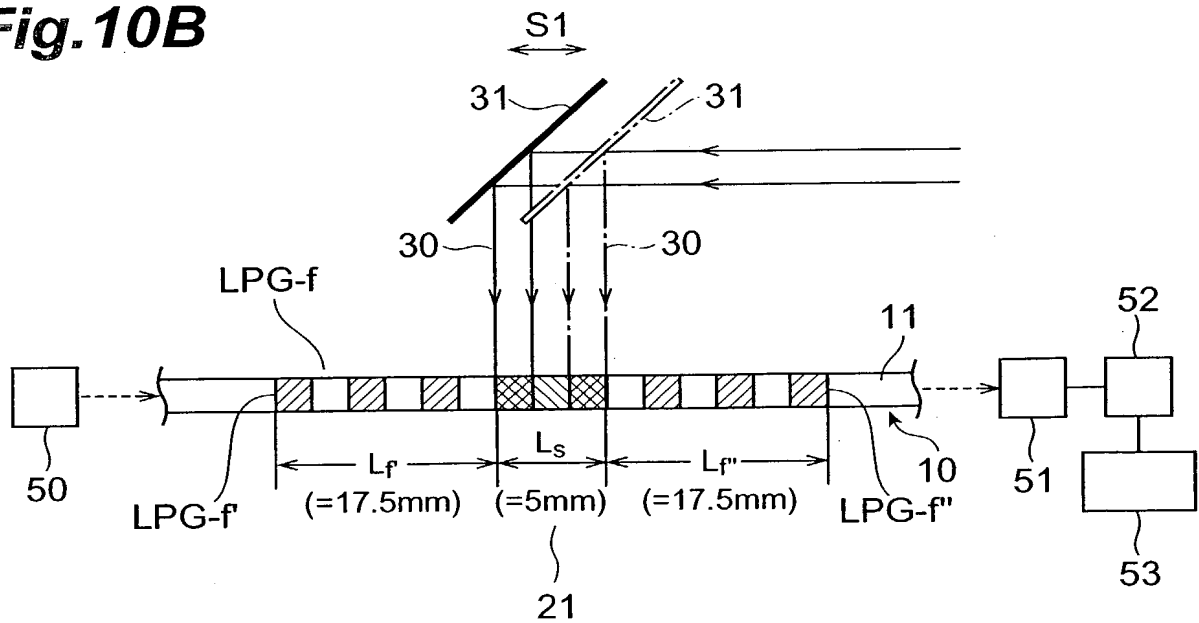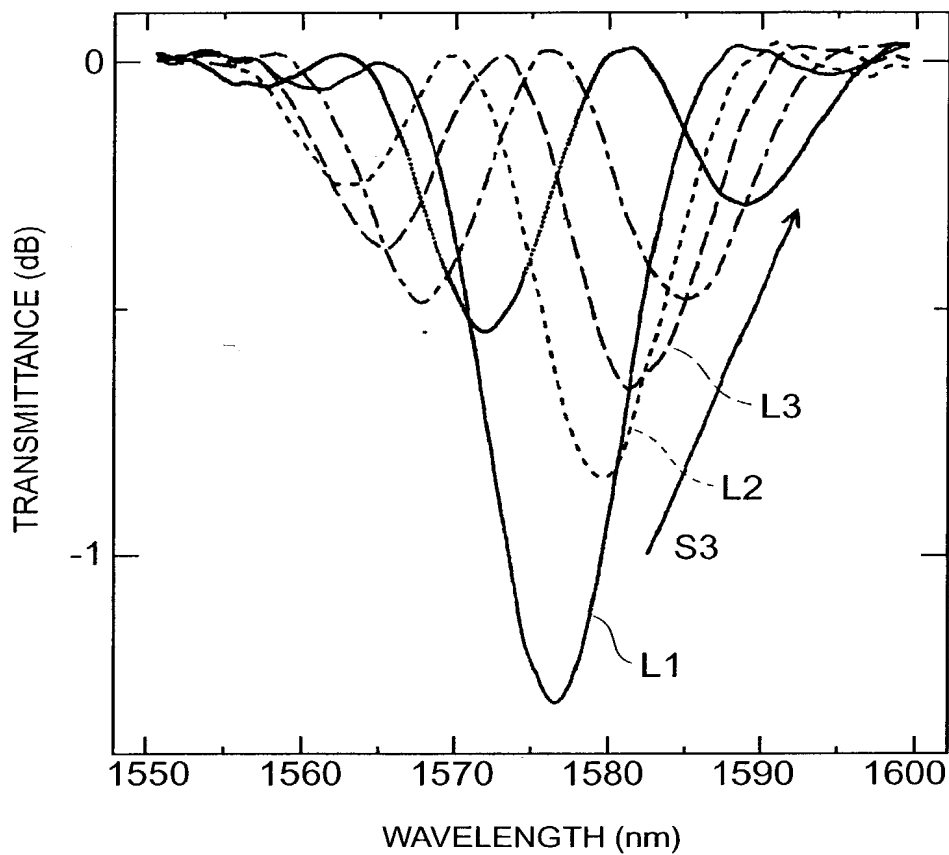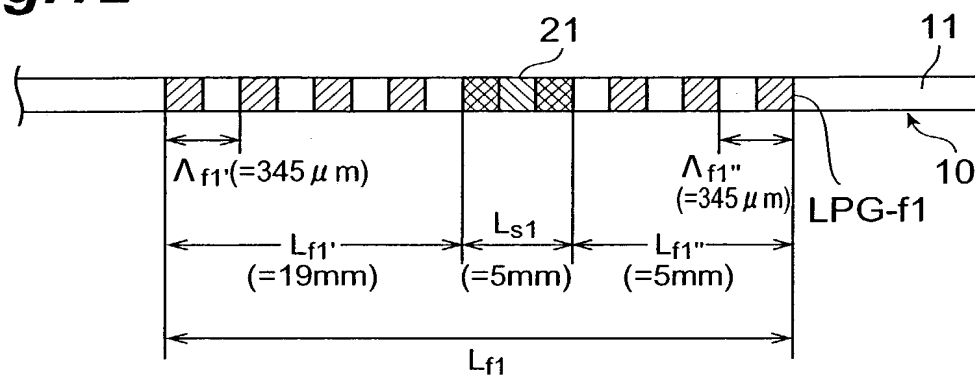
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Fig.13

Fig.14

Fig.15

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Fig.16
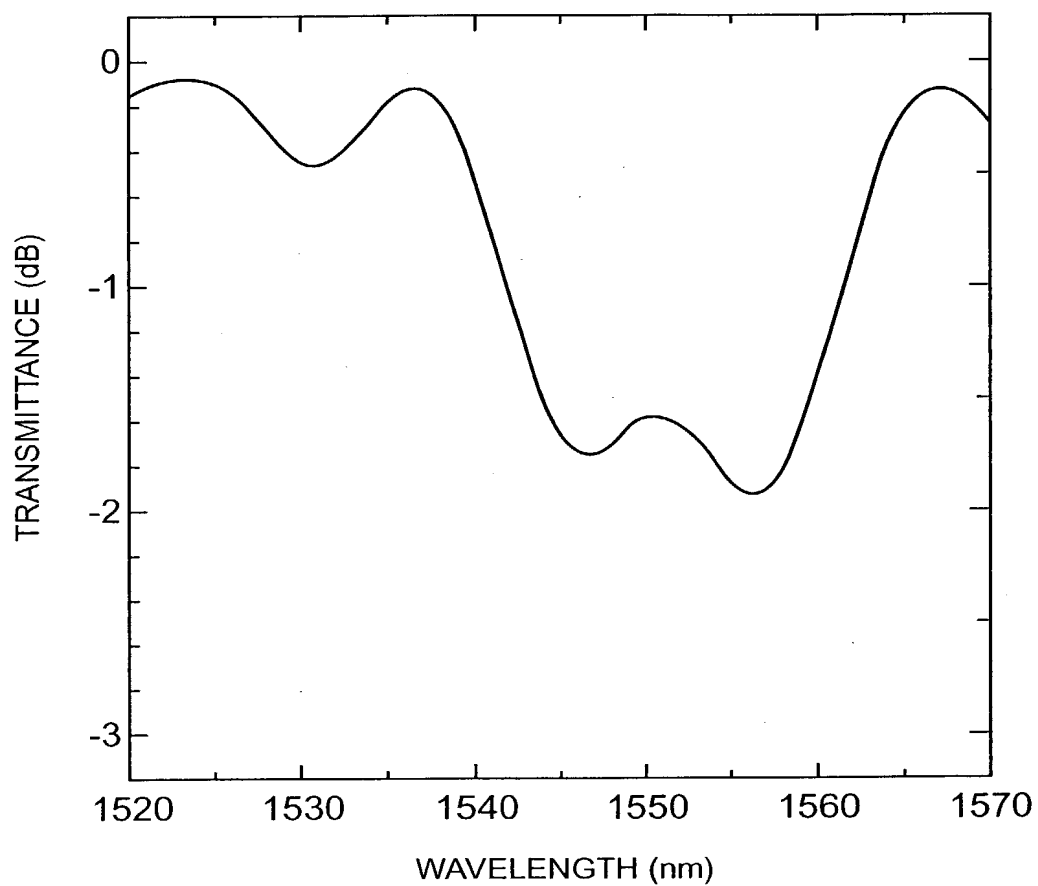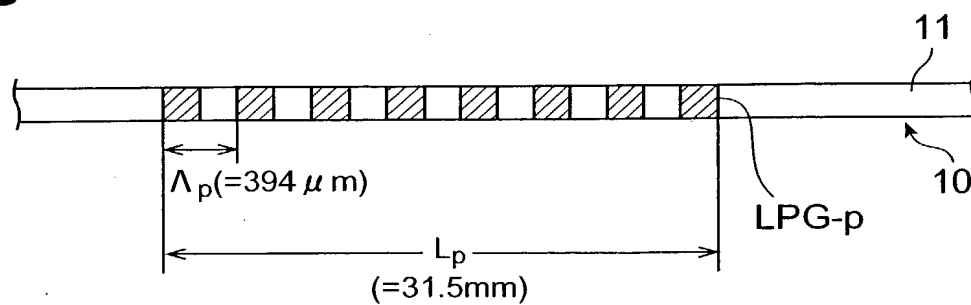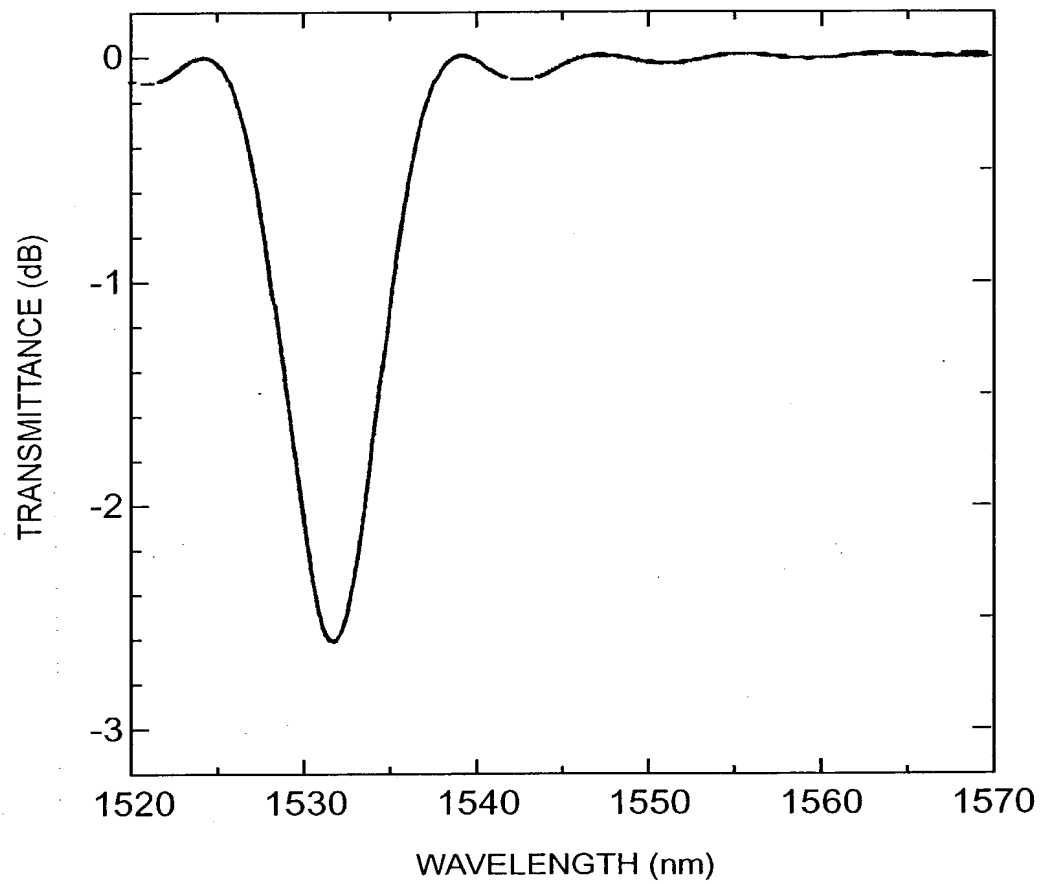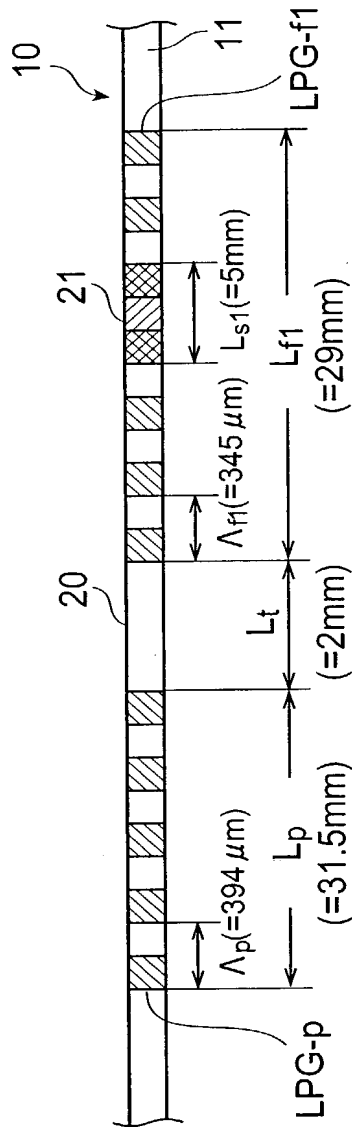
Fig.17
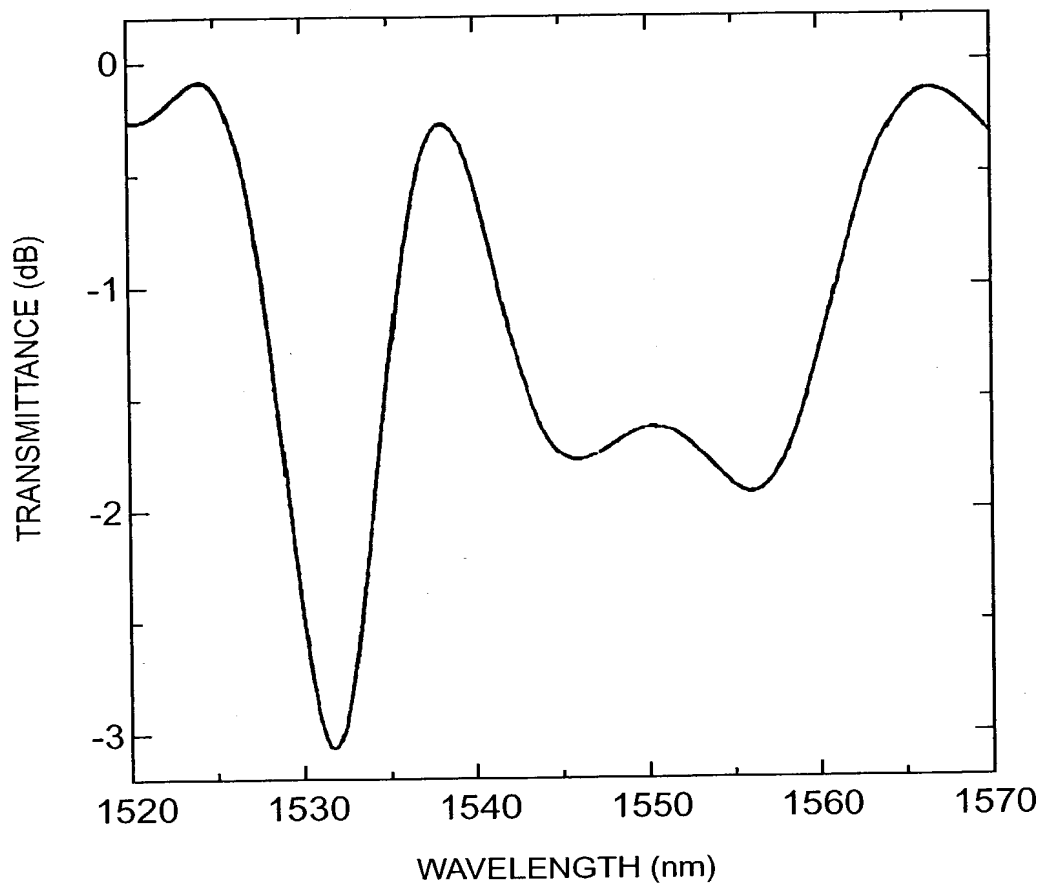
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Fig.18

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Fig.19
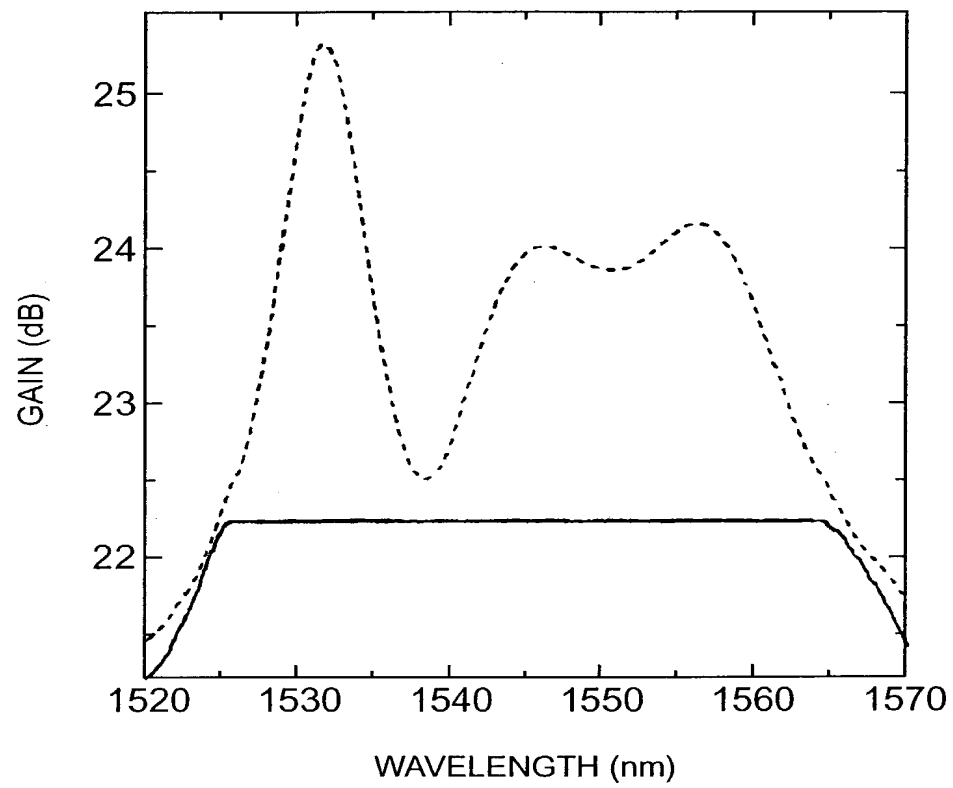
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Fig.20

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Fig.21

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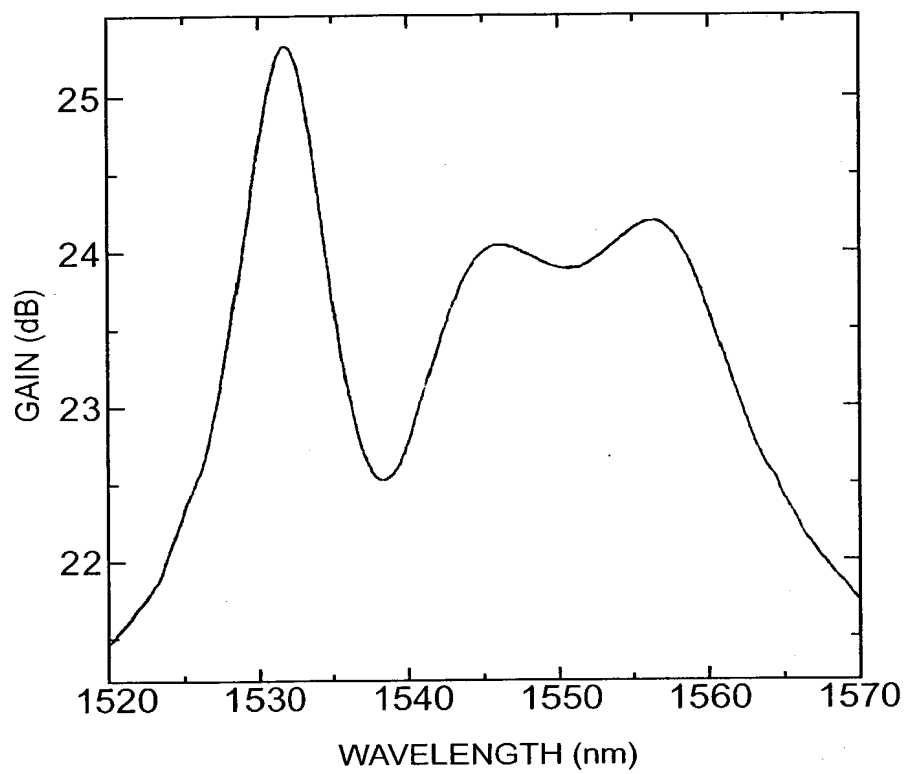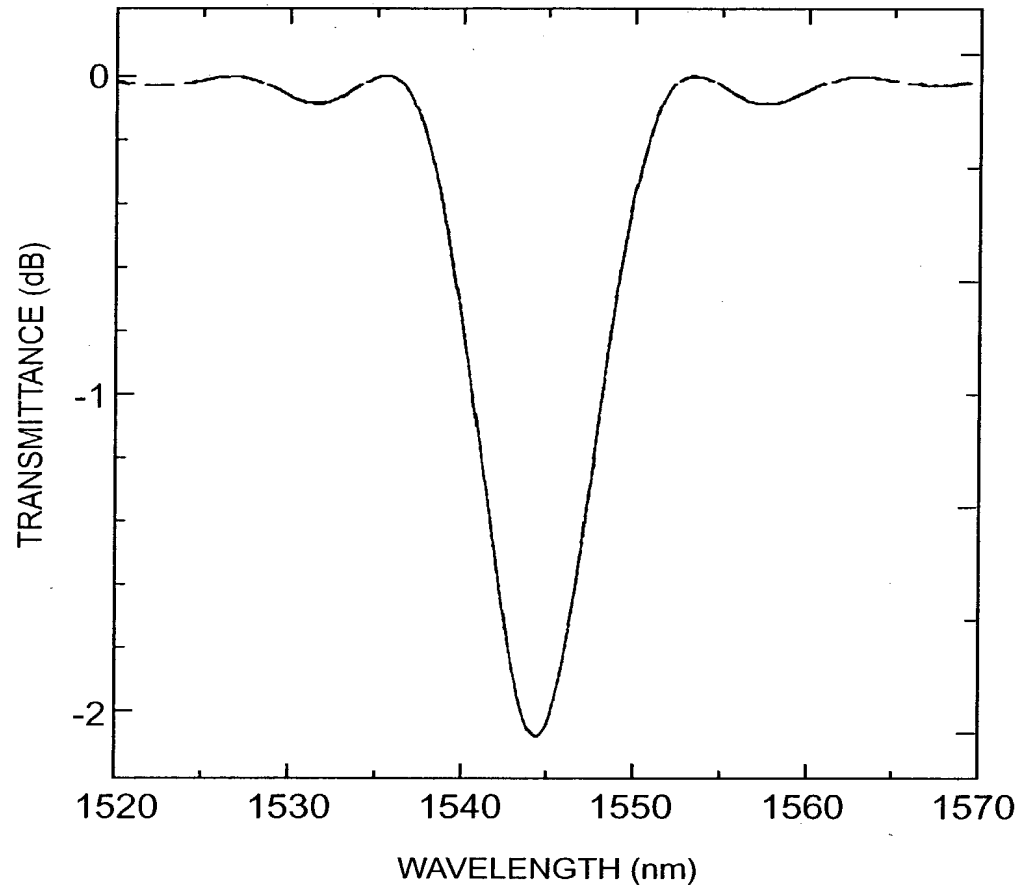
Combined Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

This declaration is of the following type:

[ ] original   [ ] supplemental

[X] national stage of PCT
[ ] divisional   [ ] continuation   [ ] continuation-in-part

My residence, post office address and citizenship are as stated next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
METHOD OF MANUFACTURING OPTICAL LOSS FILTER, AND OPTICAL LOSS FILTER

the specification of which

[ ]   is attached hereto.

[X]   was filed on _____March 18, 2002_____
          as United States Application Serial Number _____10/088300_____ and,
          was amended on _____ (if applicable).

[X]   was filed on _____September 20, 2000_____
          as PCT International Application Number ___PCT/JP00/06442___ and,
          was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority under Title 35, United States Code, Section 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

PRIOR FOREIGN APPLICATIONS, BENEFIT CLAIMED UNDER 35 USC §119(a)

Application Number	Country	Date of Filing (Day/Month/Year)	Priority Claimed Under 35 USC 119
P1999-265434	Japan	20 / September / 1999	[X]Yes [ ]No
			[ ]Yes [ ]No

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

PRIOR U.S. PROVISIONAL APPLICATIONS, BENEFIT CLAIMED UNDER 35 USC §119(e)

(Application No.)	(Filing Date)	(Application No.)	(Filing Date)
(Application No.)	(Filing Date)	(Application No.)	(Filing Date)

I hereby claim the benefit of Title 35, United States Code Section 120 of any United States application(s), or 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS
DESIGNATING THE U.S., BENEFIT CLAIMED UNDER 35 USC §120

(Application No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)
(Application No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)

POWER OF ATTORNEY: As a named inventor, I hereby appoint the registered practitioners of McDermott, Will & Emery included in the Customer Number provided below to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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